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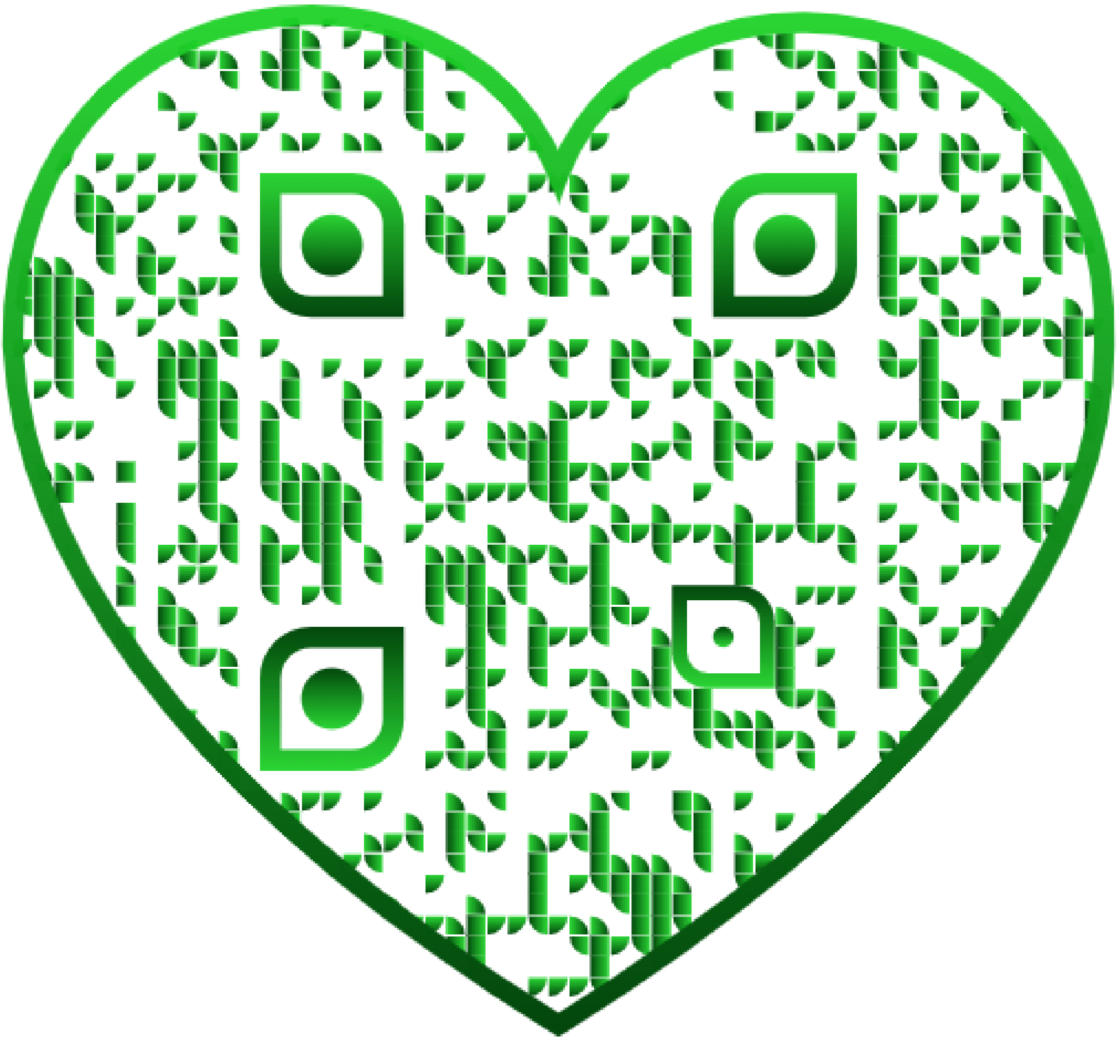
How we could find LIFE IN THE COSMOS

- WAS EARTH ONCE A RINGED PLANET?
- SKY GLOWS YOU SHOULD KNOW
- IMAGING DURING THE FULL MOON
- COMPLETE SKY EVENTS COVERAGE
- DWARFLAB 3 SCOPE REVIEWED

BONUS ONLINE CONTENT CODE p. 3

Vol. 53 • Issue 8



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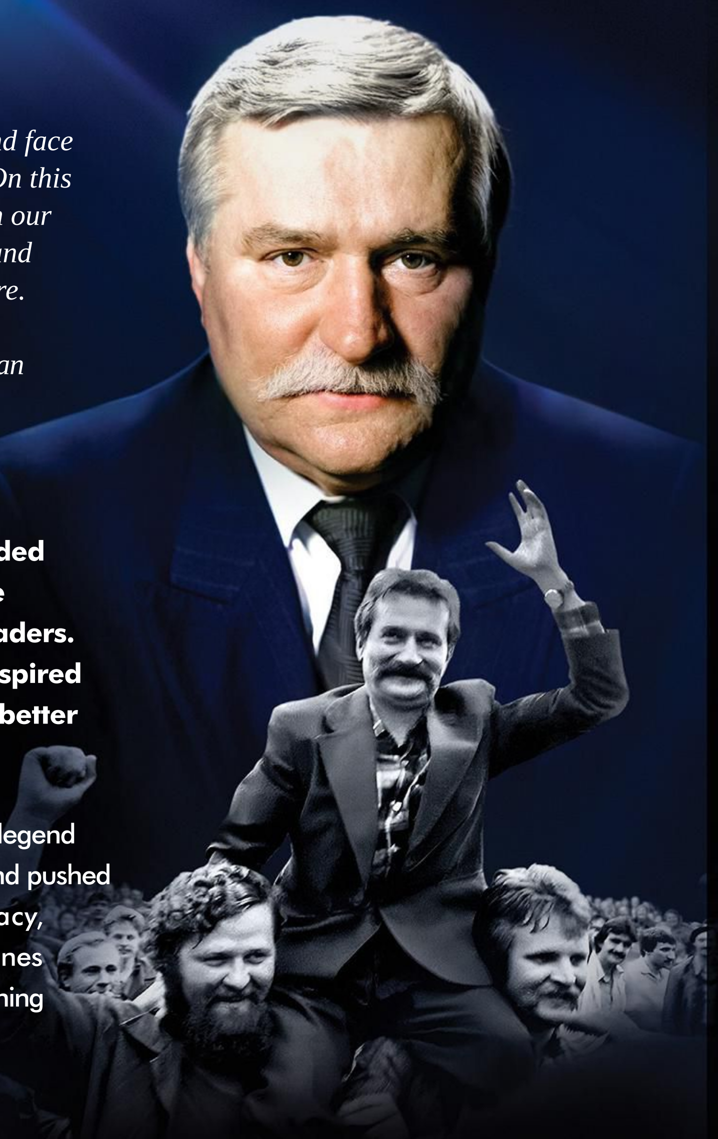

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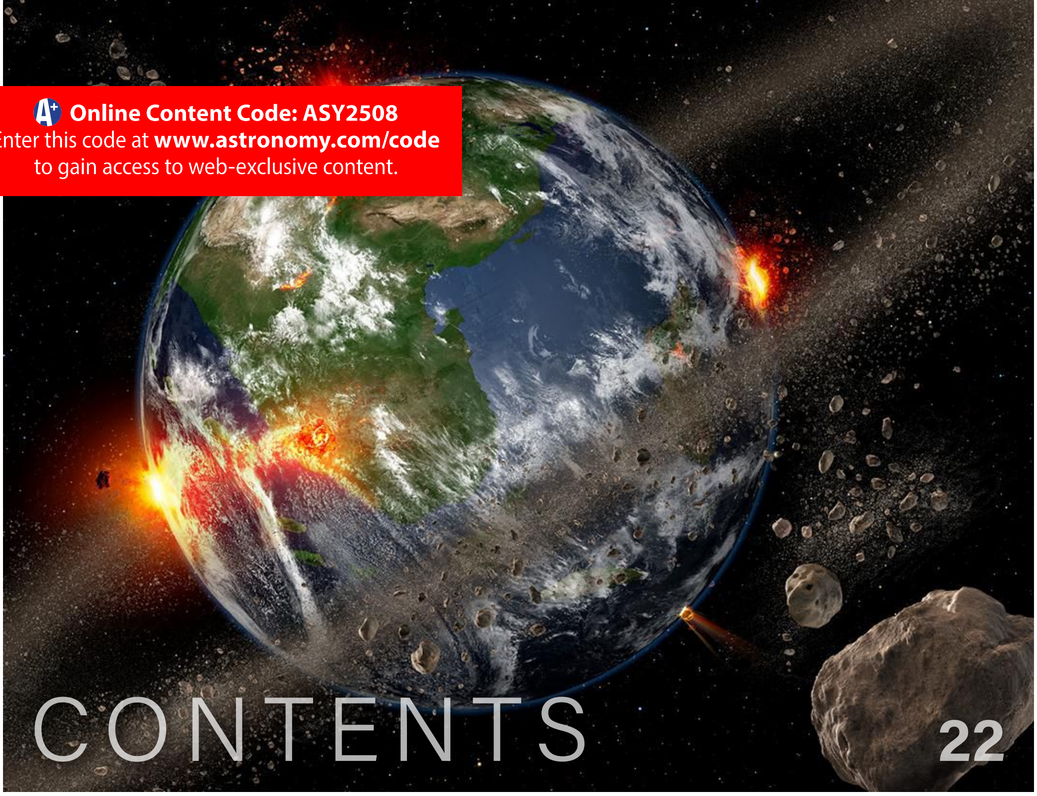

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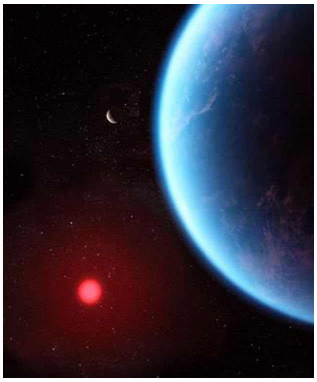

ON THE COVER

To look for life on exoplanets like this mini-Neptune, scientists are searching for ways to detect gases that indicate organic processes.

ILLUSTRATION: NASA, ESA, CSA, JOSEPH OLMSTED (STSCI); SCIENCE: NIKKU MADHUSUDHAN IOA)

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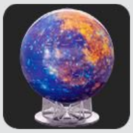

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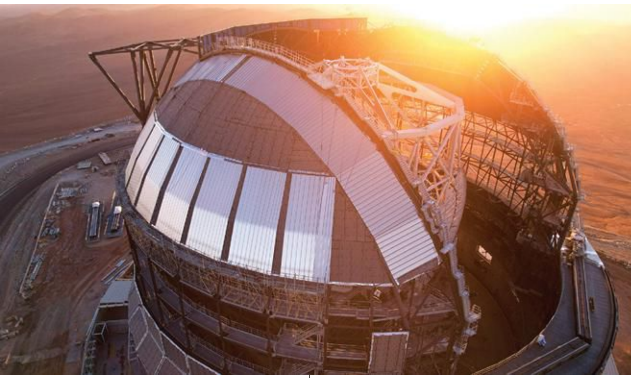
FROM THE EDITOR

Life in the universe



Very large telescopes like the 39m ELT being constructed in the Chilean desert may enable the detection of worlds hosting life near us in the galaxy. ESO/G. VECCHIA

There's a great conundrum in the cosmos. The universe is filled with places that could host life. Several hundred billion stars exist in our Milky Way Galaxy alone. The cosmos contains at least 100 billion galaxies, and maybe it's even infinite. We see planetary systems in abundance throughout the star systems near us. Spectroscopy tells us that the chemistry of the cosmos is uniform, and we see the building blocks of life, like amino acids, in strange places even in our solar system. And yet we know of only one place in the cosmos that hosts life: right here on Earth.

The challenge may come from the immensity of the cosmic distance scale, and the fact that to detect advanced life — unambiguous signals — we would have to be listening in just the right place and at just at the right time. Finding what astronomers call biosignatures, or signs of life, would probably be the first indication of our finding another planet that hosts life somewhere in our galaxy.

Of course just what would constitute a precise, unambiguous biological detection may not be so simple, as Theo Nicitopoulos explores in this month's story, "Searching for life in the Milky Way" (page 14). Finding life on another planet somewhere out there would definitely have huge effects on the psychology of humans right here. It may be one of the most Earth-shaking discoveries made in the fabric of human history. So it will have to be very clear and explainable only in that way.

For now, with a universe containing at least 10,000 billion billion planets, and with chemistry combining atoms in fixed, orderly ways, it's highly likely that the cosmos is filled with life. Several years ago, astronomers at the University of Chicago and Northwestern University estimated the Milky Way alone could contain 60 billion habitable planets.

If we make a breakthrough discovery, will you be ready to no longer feel so alone?

Yours truly,

David J. Eicher
Editor-in-Chief

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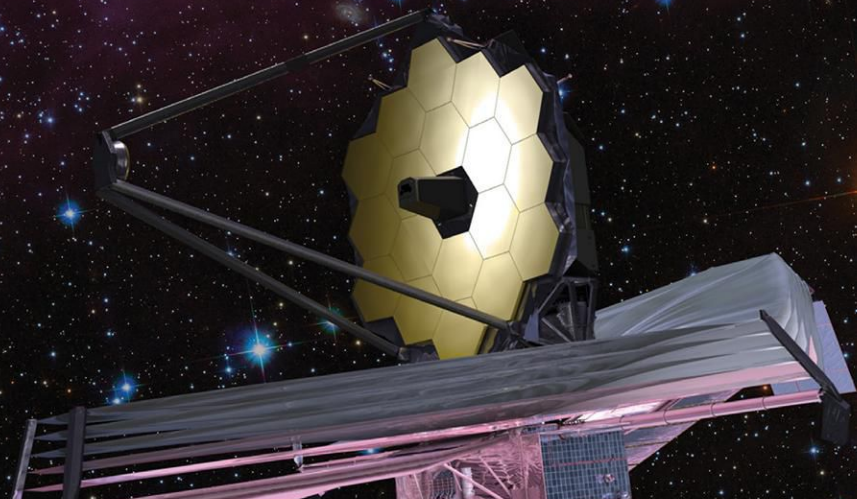

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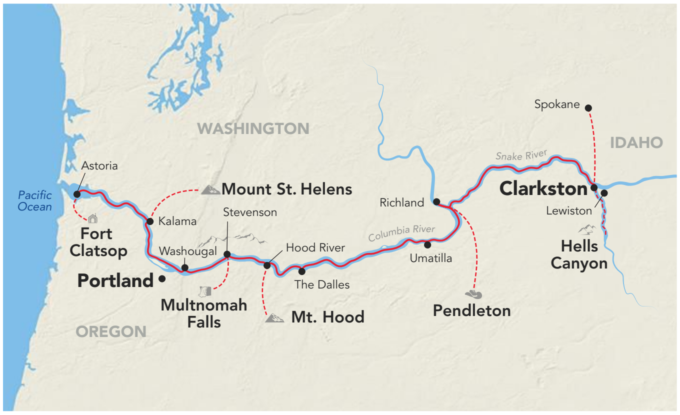
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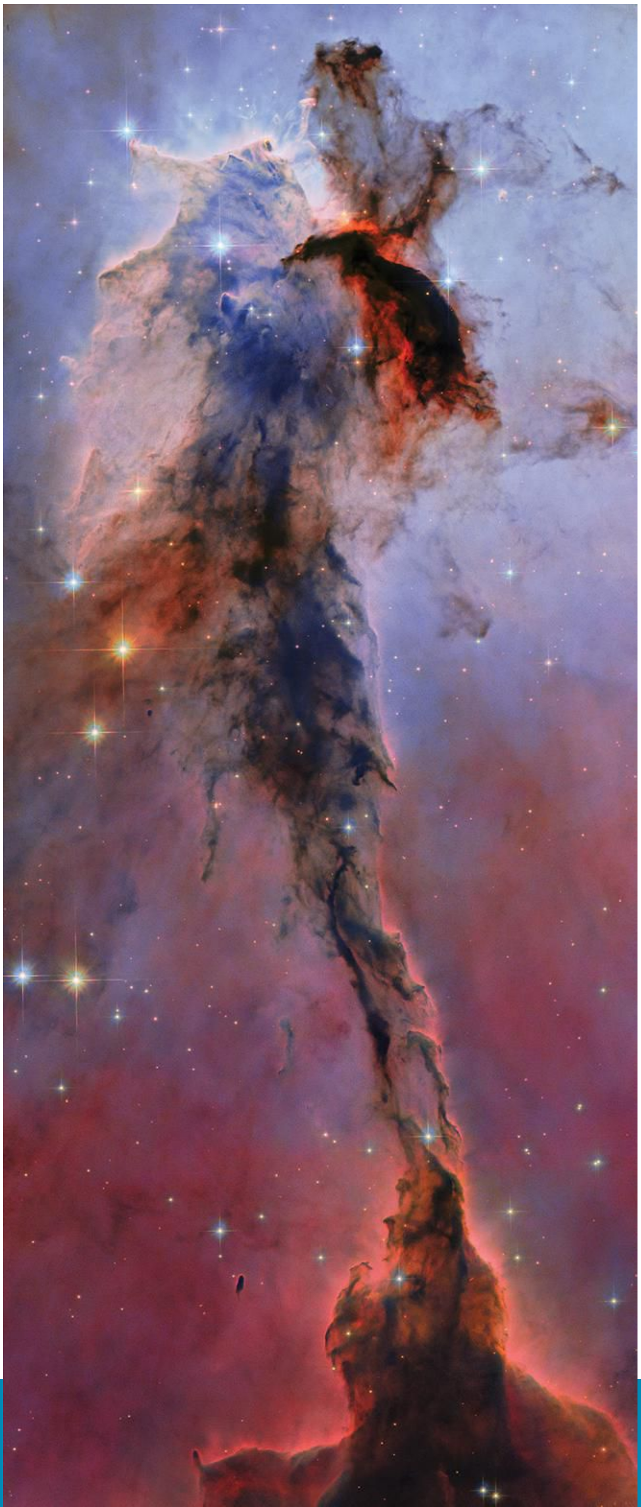
SNAPSHOT

HUBBLE ILLUMINATES A DARK, DUSTY PILLAR

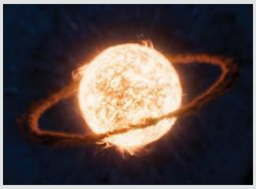
The updated photo celebrates the space telescope's 35th birthday.



Looking like a bird ready to take flight from atop a post, this dusty filament within the Eagle Nebula (M16) appears in intricate detail as seen by the Hubble Space Telescope. The nebula lies some 7,000 light-years away and surrounds an open star cluster. This pillar stretches 9.5 light-years long and is composed of cold dust and hydrogen gas, which serve as material to create new stars. These stars generate powerful winds and ultraviolet light, which have eroded the cloud into its current shape. Eventually the entire tendril will be destroyed by the radiation from ongoing star formation. The colors highlight different wavelengths of emission. Blue is from ionized oxygen, red is hydrogen, and orange is starlight that has cut through the dust. This photo was taken in 2005, but was reprocessed and released in celebration of Hubble's contribution to science over the past 35 years. –SAMANTHA HILL

ESA/HUBBLE & NASA, K. NOLL. RIGHT FROM TOP: NASA, ESA, CSA, RALF CRAWFORD (STSCI); JANNICKE MIKKELSEN/FRAM2/SPACEX; NASA/JOHNS HOPKINS APL/STEVE GRIBBEN

HOT BYTES



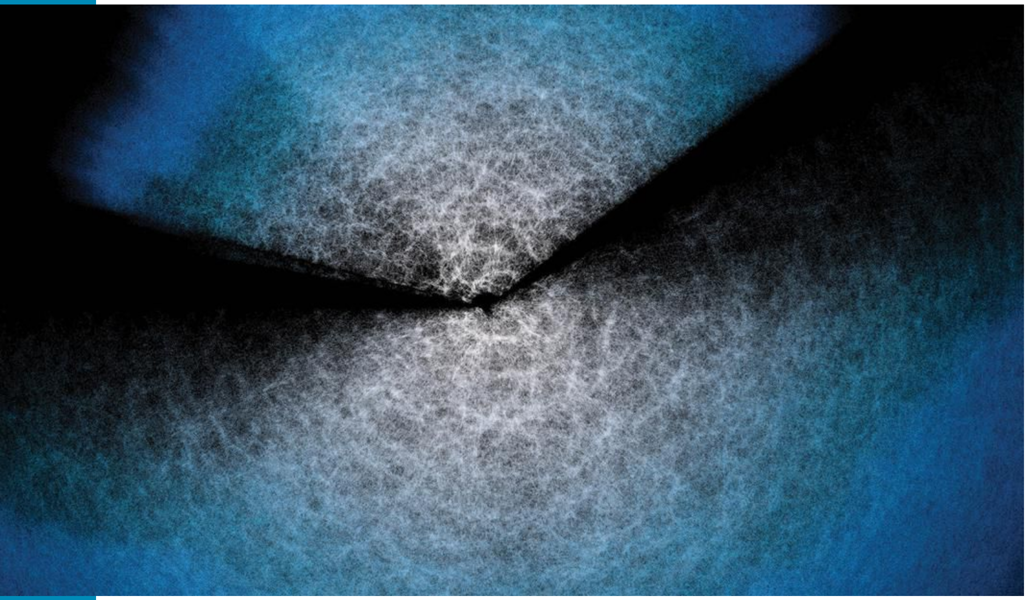
BLAZE OF GLORY
In 2020, the Zwicky Transient Facility caught a flash of light when a planet was swallowed by its star. New data from the James Webb Space Telescope show the star did not swell in old age to engulf the planet; instead, the planet gradually fell closer and plunged to its doom.

POLAR FLIGHT
The private Fram2 mission launched March 31 to a polar orbit, making its crew the first astronauts to fly over Earth's poles. The mission lifted off on a SpaceX Falcon 9 rocket from Kennedy Space Center and splashed down April 4.

DRAGONFLY GREENLIT
NASA announced April 24 that the Dragonfly mission has passed its critical design review, paving the way for its construction. The nuclear-powered quadcopter drone will explore Saturn's moon Titan, studying whether it could harbor life.

DARK ENERGY MAY BE CHANGING

Major survey results hint that dark energy is not constant, raising questions about the standard cosmological model.



LOOKING OUT. This fan-shaped plot shows objects in the two main regions of the sky (with Earth at the center) covered by the Dark Energy Spectroscopic Instrument (DESI), which created the largest 3D map of the universe to date. Darker, bluer colors indicate greater distance from us. DESI COLLABORATION/DOE/KPNO/NOIRLAB/NSF/AURA/R. PROCTOR

» Our universe has been expanding since the Big Bang — and that expansion is accelerating. The standard model of cosmology ascribes this to a repulsive force pushing space apart, called dark energy. For decades, cosmologists assumed this force was constant, an inherent and unchanging property of space.

But findings released March 19 from two of the largest cosmological surveys to date — the Dark Energy Spectroscopic Instrument (DESI) survey and the Dark Energy Survey (DES) — add to mounting evidence suggesting that the force from dark energy may be changing over time.

DESI researchers analyzed a 3D map containing almost 15 million galaxies and quasars. "The assumption was that we would just obtain the highest-precision measurement confirming the constant," says Stephanie Juneau, an astronomer at the National Science Foundation's NOIRLab and a DESI data team member. "It was actually a huge surprise that we found some hint of deviation."

Meanwhile, DES scientists, using separate methods across six years of observations, found similar anomalies that suggest the standard model may not tell the full story.

Alone, these data do not significantly challenge the standard model. But combined with external measurements, including data from the cosmic microwave background (the afterglow of the Big Bang), supernovae studies, and gravitational lensing, tensions begin to emerge.

"What was most convincing for me is that the evidence is coming from different directions. And it can't be that all these different directions of different data sets conspire to give the same wrong answer," says Mustapha Ishak-Boushaki, a theoretical astrophysicist at the University of Texas at Dallas and co-chair of the working group that analyzed the DESI data.

EVOLVING, NOT CONSTANT

In Einstein's equations describing the universe, the cosmological constant — thought to represent dark energy's force — offers a straightforward way to explain accelerated expansion. Quantum field theory predicts that empty space contains energy, called vacuum energy — one candidate for dark energy. But vacuum energy should act like a repulsive force more than 40 orders of magnitude stronger than what astronomers observe.

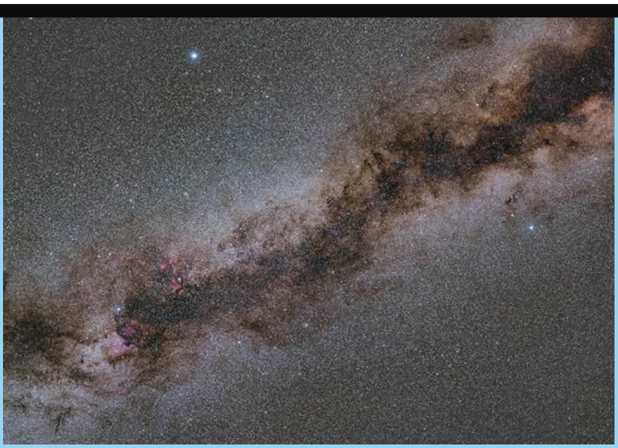
Evolving dark energy could resolve this contradiction by giving astronomers new theoretical frameworks to explore, from modified theories of gravity to energy fields that naturally evolve over time. "The hope is back that [dark energy] is not a cosmological constant, it's something different," says Ishak-Boushaki. "Do we know what it is exactly now? No, but the door has opened for us to find it."

The current level of statistical confidence in the combined results is around 4.2 sigma, approaching the 5-sigma threshold typically required for a scientific discovery to be accepted. At that level, the probability of the result being a statistical fluke drops to less than one in a million. Future DESI data could push the signal beyond the 5-sigma discovery threshold. And upcoming projects like the Vera C. Rubin Observatory's Legacy Survey of Space and Time and NASA's Nancy Grace Roman Space Telescope can provide cross-checks.

"I'm not going to hold a funeral for the standard cosmological model," says Jessie Muir, a cosmologist at the University of Cincinnati and member of the DES team. "I'm cautiously excited. It's something to keep an eye on and prod at and really try to make sure we understand."

— MACKENZIE WHITE

A LOCAL 'DARK GALAXY'



CLOUDY SKIES. High-velocity clouds are made of gas traveling much faster than the rotating plane of the Milky Way, imaged here.

GIUSEPPE DONATIELLO

Research published April 18 in *Science Advances* suggests that a fast-moving cloud of gas near the Milky Way may not be a cloud at all, but rather a small galaxy made mostly of dark matter.

The galaxy, called AC G185.0–11.5, is part of a larger structure called a high-velocity cloud. These are clumps of hydrogen moving several hundred mph faster than gas in the Milky Way's plane, thought to be material falling onto the galaxy from outside.

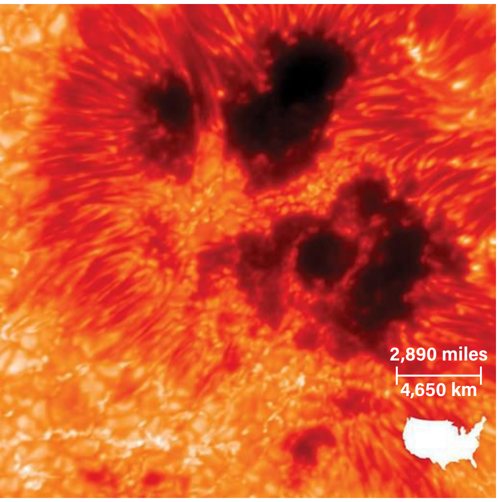
Using radio data from the Arecibo Observatory in Puerto Rico and the Five-hundred-meter Aperture Spherical Telescope in China, the authors discovered a clump of gas with properties of a rotating disk galaxy — but without any visible stars.

Astronomers believe such so-called dark galaxies have very little material inside them to form stars. Instead, they are dominated by dark matter. In fact, says study co-author Ming Zhu, an astrophysicist at the Chinese National Academy of Sciences, AC G185.0–11.5 appears to contain 21 times more dark matter than normal matter.

The giveaway comes from AC G185.0–11.5's motion, which Zhu says, "reveals that the gas is rotating [in] a disk-like structure. … There should be dark matter inside to control the rotation." The team calculates that AC G185.0–11.5 contains about 300 million Suns' worth of mass, although there is a high degree of uncertainty.

Follow-up with observatories like the James Webb Space Telescope and the Very Large Array could help determine the nature and contents of AC G185.0–11.5. If it is confirmed to be a dark galaxy, its proximity to the Milky Way could make it a perfect laboratory to better study the role of dark matter in galaxies, whether or not they are dominated by it. — JOHN WENZ

Solar scope's sunspot shots stun



VTF/KIS/NSF/NSO/AURA

The first-light observation of the Visible Tunable Filter (VTF) on the U.S. National Science Foundation's Daniel K. Inouye Solar Telescope (DKIST) — the world's most powerful solar telescope, near the summit of Maui's Haleakalā in Hawaii — provides an exciting glimpse of its capabilities. The VTF is designed to isolate specific wavelengths of light and scan through them quickly, capturing hundreds of narrow-band images in just seconds. This image, published April 24, was taken at a wavelength of 588.9 nanometers, and each pixel corresponds to 6.2 miles (10 kilometers) of the solar surface. An image of the continental U.S. is superimposed in the bottom right corner for scale. The VTF will be fully operational in 2026. — DANIELA MATA

QUICK TAKES

TWO-FACED STARS

The discovery of two more "double-faced" white dwarfs — a bizarre class of stars whose surfaces have alternating patches of hydrogen and helium — was published April 1, bringing the number of such objects found to seven.

NEUTRINOS, THEY ARE VERY SMALL

The Karlsruhe Tritium Neutrino (KATRIN) experiment has made the most precise measurement yet of the mass of neutrinos — "ghost particles" that hardly interact with matter. In results announced April 10, the team found neutrinos are no larger than 0.45 electron volt, refining the previous upper limit by a factor of 2.

SUN FILTER

Carbonaceous (carbon-rich) asteroids — carriers of water and organic molecules — are common in space, yet account for only 5 percent of recovered meteorites. New research published April 14 in *Nature Astronomy* suggests this is because such meteoroids break apart from being heated as they pass near the Sun.

AFRICA'S SPACE AGENCY

The African Space Agency (AfSA) was inaugurated in a ceremony April 20 at its headquarters in Cairo. Modeled on the European Space Agency, AfSA is a continent-wide organization, counting as members all 55 nations of the African Union.

ROUND AND ROUND

A team of researchers has proposed that the universe may be slowly spinning, completing a rotation once every half-billion years. This motion could explain why the local universe appears to be expanding faster than standard cosmological models predict, a discrepancy called the Hubble tension. — MARK ZASTROW

DRILL SITE. This hole shows where Curiosity drilled into the Cumberland rock in May 2013. The sample taken has been analyzed numerous times, leading to the discovery of organic molecules. NASA/JPL-CALTECH/MSSS

Large organic molecules found on Mars

» **NASA'S CURIOSITY ROVER** has detected organic molecules that are the largest yet found on the Red Planet, showing that complex chemistry occurred in Mars' past. Organic molecules are the building blocks of life, although they can also be produced by geological processes.

The rover found decane, undecane, and dodecane, named for the 10, 11, and 12 carbon atoms they each contain, respectively. Researchers think these molecules might, in turn, be broken off from even larger carboxylic molecules. Carboxylic or fatty acids often form cell walls but also occur through nonliving processes, especially around hydrothermal vents.

Curiosity found the molecules in a rock dubbed Cumberland in an extinct lakebed within Gale Crater. The Cumberland sample, drilled in 2013, has been investigated several times. The new study, published March 24 in *Proceedings of the National Academy of Sciences*, was led by Caroline Freissinet of the French National Centre for Scientific Research in the Laboratory for Atmospheric, Observations, and Space, who has led previous investigations of the sample as well.

Large molecules indicate more complex chemistry, as the processes that build them require more time and more exotic situations than basic compounds. But they are also delicate. Scientists had been uncertain that such large molecules would have survived the harsh radiation Mars' surface has suffered for billions of years.

The discovery proves that Mars did have the environments to build complex molecules, regardless of their origin. And the molecules' survival since their creation some 3.7 billion years ago means actual biosignatures could have survived, even if life perished long ago.
— KOREY HAYNES

GALAXY CLEARS HYDROGEN 'FOG'

The early universe was a dark place, filled with a fog of neutral hydrogen. But during the epoch of reionization, energetic ultraviolet (UV) light flooded the cosmos; the light excited the hydrogen gas and the universe has been transparent to UV light ever since.

This timeline is supported by theory and indirect evidence. And the James Webb Space Telescope's (JWST) ability to see some of the earliest galaxies is helping scientists observe this transformative era of the universe directly.

In a paper published March 26 in *Nature*, researchers report the discovery of a galaxy called JADES-GS-z13-1-LA, found at a time when the universe was just 330 million years old. Lead author Joris Witstok, a postdoctoral fellow at the University of Copenhagen, says that while it's not the most distant galaxy ever seen, it is the first and earliest galaxy seen taking part in the process of reionization. It is leaking enough UV photons to excite hydrogen beyond the galaxy's bounds, creating a transparent bubble 650,000 light-years across.

Scientists aren't sure of the actual source of the galaxy's UV photons. They could have been emitted by its stars — possibly the first or second generation of stars ever born. UV photons could also have come from the disk of plasma around an accreting supermassive black hole. Regardless of the source, the find helps further constrain the onset of reionization and shows the power of JWST in capturing such distant galaxies in detail. — J.W.

EARLY START. The distant galaxy JADES-GS-z13-1-LA (indicated with an arrow) shows signs of reionization just 330 million years after the Big Bang. ESA/WEBB, NASA & CSA, JADES COLLABORATION, J. WITSTOK, P. JAKOBSEN, M. ZAMANI (ESA/WEBB)

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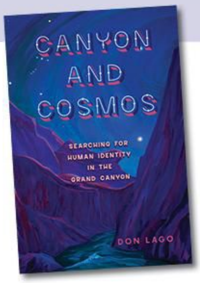
CANYON AND COSMOS:
SEARCHING FOR HUMAN IDENTITY IN THE GRAND CANYON.
By Don Lago



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Abstract

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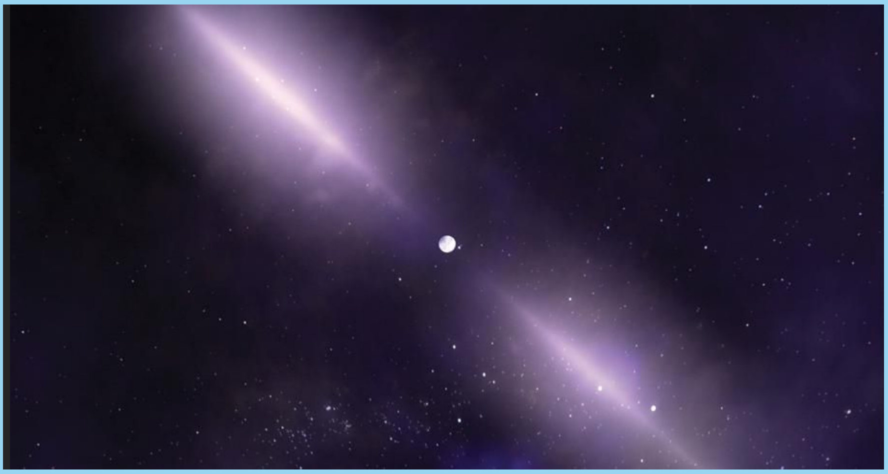
SLOW-MOTION PULSAR COULD BE MISSING LINK



COSMIC CLOCK. Pulsars, such as the one imagined here, are rapidly spinning neutron stars. Traditional pulsars' beams are powered by their rotation, but only if they spin fast enough. NASA'S GODDARD SPACE FLIGHT CENTER

PULSARS ARE RAPIDLY SPINNING neutron stars that act like cosmic lighthouses. But astronomers recently found a pulsar blinking in slow motion — something that shouldn't be possible. The unexpected find was published March 28 in *The Astrophysical Journal Letters.*

Pulsars are powered by rotation. They are born spinning quickly; as they gradually slow, the energy lost is converted into the radio beams that sweep over Earth with each rotation. The fastest pulsars blink tens of thousands of times per minute, while the slowest flash every 10 seconds. But since 2022, astronomers have found a handful of objects, called long-period transients, with periods of minutes to hours. Long-period transients are spinning too slowly for further loss in rotational energy to generate beams as strong as the ones we see. So, they can't be powered by the same mechanisms as faster pulsars.

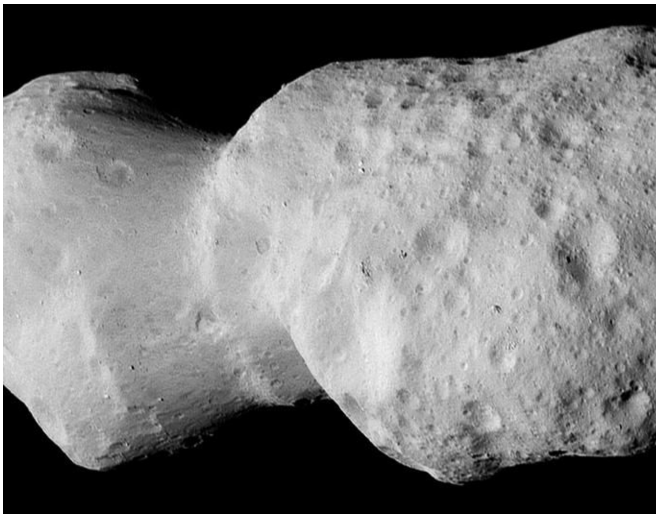
The new pulsar, PSR J0311+1402, has a 41-second period — between traditional pulsars and long-period transients. Astronomers think it could be a missing link between the two populations. Its luminosity, period, and other characteristics strongly indicate it's a pulsar. But it's spinning too slowly to be powered solely by rotation. Studying this strange beacon and more like it could reveal how long-period transients generate their beams.

The find, which was enabled by a new data-processing system on the Australian Square Kilometre Array Pathfinder radio telescope, is "incredibly exciting," says lead author Yuanming Wang, a postdoctoral researcher at Swinburne University in Australia. "But what's even more exciting is that the new technique we used is opening the door to finding more hidden objects in the cosmos. I think there should be more objects like this waiting to be discovered."

—ASHLEY BALZER VIGIL

Donaldjohanson's strange shape revealed by Lucy

NASA's Lucy spacecraft flew past the asteroid 52246 Donaldjohanson on April 20, coming within 600 miles (920 kilometers) of the main-belt world. Images taken by the craft's high-resolution camera revealed that the asteroid is bigger than expected: 5 miles (8 km) long and 2 miles (3.5 km) at its widest. Donaldjohanson also has an unusual peanutlike shape, with two lobes connected by a narrow neck. This classifies it as a contact binary, formed when two objects come together. "Asteroid Donaldjohanson has strikingly complicated geology," said Hal Levison, principal investigator for Lucy at the Southwest Research Institute, in a NASA press release. On Aug. 12, 2027, Lucy will arrive at its next destination: 3548 Eurybates and its satellite, Queta. Eurybates and the rest of Lucy's targets are Trojan asteroids gravitationally linked with Jupiter. —S.H.



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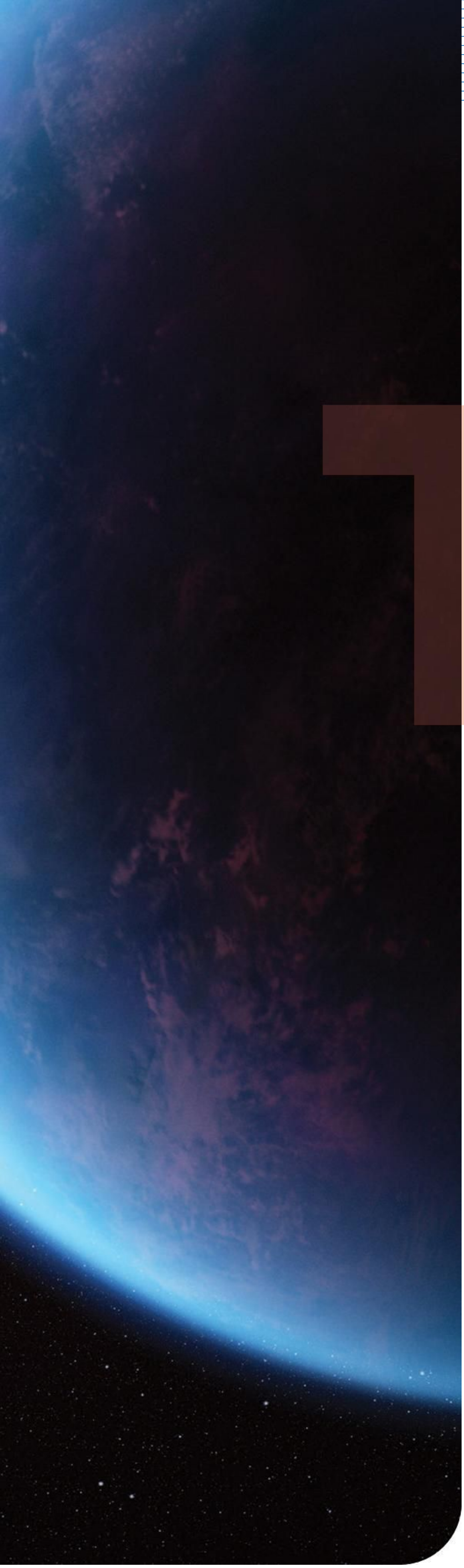
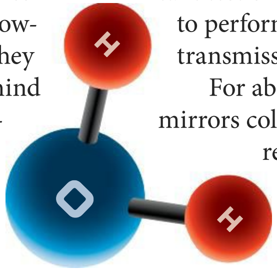


Scientists are turning to simulations and experiments to understand how life-indicating molecules behave.

BY THEO NICITOPOULOS

THE NEXT TIME YOU LOOK AT A STAR, imagine a rocky planet orbiting at just the right distance for a climate that supports liquid water on its surface. Picture thick forests upon vast landscapes teeming with wildlife. Or consider a water world devoid of land where strange marine life swims beneath a hydrogen sky. Maybe even more exotic life-forms inhabit oceans filled not with water but hydrocarbons like methane.

For the first time in human history, these musings are not idle fantasy: Scientists can search for signs of life in the atmospheres of alien planets by aiming powerful telescopes at them as they cross in front of and slip behind their stars, studying the telltale dimming of light.



These techniques are entering a new phase thanks to NASA's James Webb Space Telescope (JWST) and even more powerful upcoming scopes. The hope is that scientists will uncover biosignatures — chemicals like oxygen or methane that can indicate life. But it takes great care to determine whether these signals are due to life and not some other phenomenon mimicking life's chemical fingerprint.

To solve that puzzle, scientists are conducting experiments and computer simulations to evaluate what gases could exist in exoplanet atmospheres. If astronomers are going to find signs of life beyond our solar system, they will need synergy between observatories and laboratories — and perhaps a bit of luck.

The curious case of WASP-39 b

On July 10, 2022, researchers directed JWST toward a star slightly smaller than our Sun that hosts a gas giant known as WASP-39 b. With a mass similar to Saturn and a temperature of some 1,650 degrees Fahrenheit (900 degrees Celsius), the planet is hardly life-friendly. But as one of the first exoplanets that JWST studied, WASP-39 b was an important test of the telescope's ability to perform a technique called transmission spectroscopy.

For about eight hours, JWST's mirrors collected photons of infrared light, including a roughly three-hour period when the planet transited in front of its star. This meant some starlight filtered through the thin layer of atmosphere surrounding the planet — and certain wavelengths of infrared light were absorbed by its gases. When the rest of the light reached the telescope's instruments, it was split into its individual wavelengths, akin to how a prism separates light into a rainbow. By comparing the data from the transit to those taken before and after, scientists obtained a spectrum showing the fraction of light blocked at different wavelengths during the transit by different atmospheric gases.

An atmosphere rich in hydrogen and water vapor shrouds the mini-Neptune exoplanet K2-18 b, shown in this artist's concept. Beneath the clouds, a liquid ocean might exist on the surface of a rocky body that could sustain life. ILLUSTRATION: NASA, ESA, CSA, JOSEPH OLMSTED (STSCI); SCIENCE: NIKKU MADHUSUDHAN (IOA)

THE ROLE OF SPECTROSCOPISTS

Spectroscopy is the study of how light interacts with matter. Single atoms, for example, absorb light that has wavelengths that match the exact energy required to move their electrons to higher energy levels. On a spectrum, the absorptions appear as distinct dark lines because that color of light disappears.

But molecules — assemblages of multiple atoms — are more complex. This is because they have the ability to absorb wavelengths of infrared light that match the frequencies at which their bonds vibrate (e.g., bend and/or stretch), which depend on their structure. Molecules can also rotate at the same time they vibrate, especially at higher temperatures, which broadens the wavelengths of light they can absorb. This makes the spectral features less distinct and harder to identify.

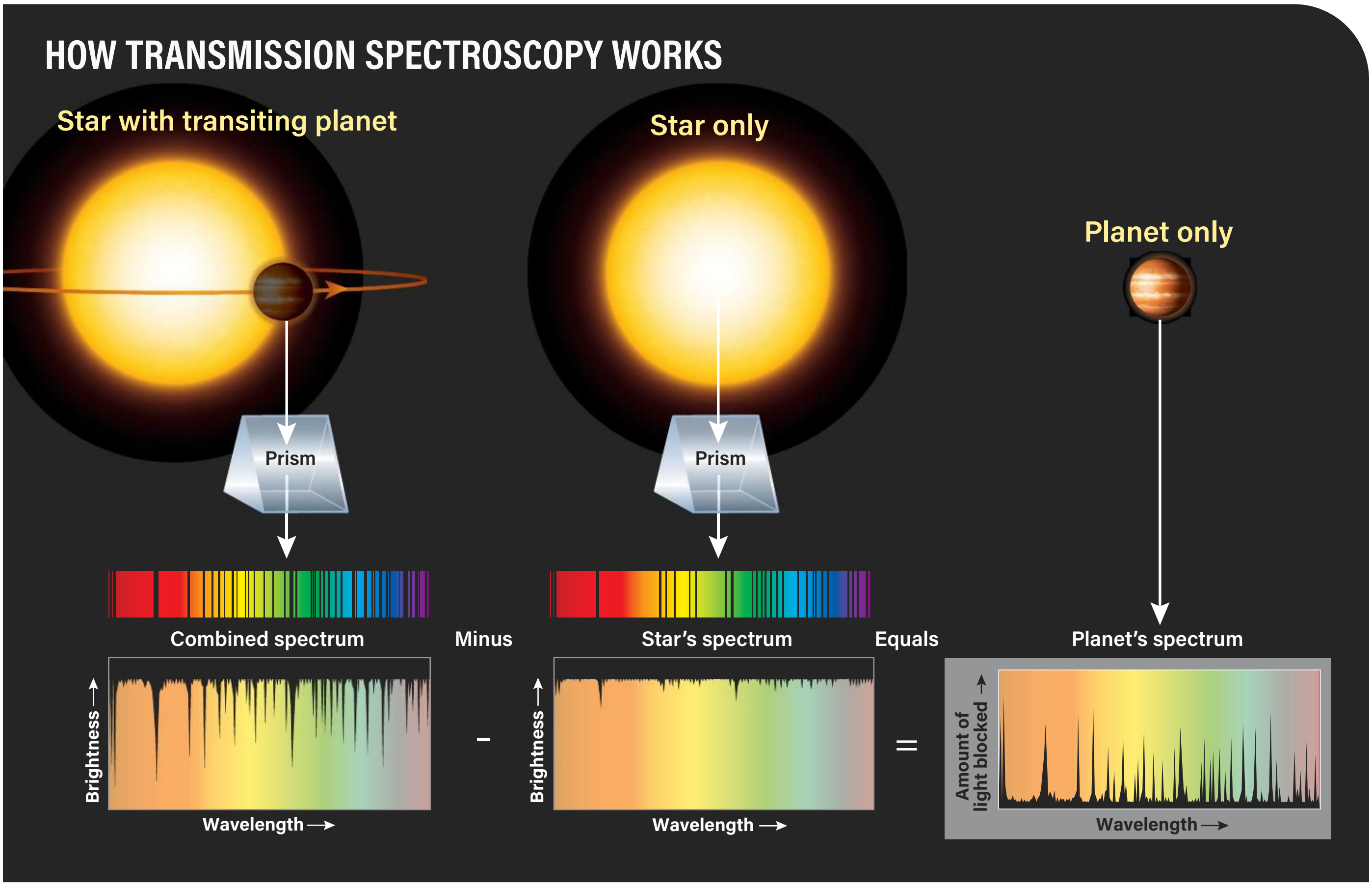
To determine which unique wavelengths cause a molecule to resonate, researchers fire infrared light at gases in laboratories and analyze the absorption data. To date, molecular spectroscopists have identified the vibrational frequencies of 100 molecules — a tremendous achievement, considering the complex behavior of molecules. — *T.N.*

Some of these gases in the spectrum were straightforward to identify. For instance, scientists know that carbon dioxide (CO_2) molecules absorb light at a wavelength of 4.26 microns, thanks to lab experiments and calculations conducted by molecular spectroscopists. “Our basic way of building a model of how molecules absorb light is from how it works at room temperature and then performing the calculations for higher temperatures,” says molecular spectroscopist Jonathan Tennyson of University College London. This is helpful for studying hot worlds like WASP-39 b.

Astronomers were also able to identify water vapor (H_2O), carbon monoxide (CO), and sodium gas (Na) in the JWST spectrum of the gas giant’s atmosphere.

But they also found a slight dimming at around 4.05 microns that they could not link to any molecule. Their models hadn’t predicted any gases in the planet’s atmosphere that would absorb at that wavelength. But when it showed up again in another JWST spectrum, “we started to feel comfortable that it is real,” says astronomer Jacob Bean of the University of Chicago.

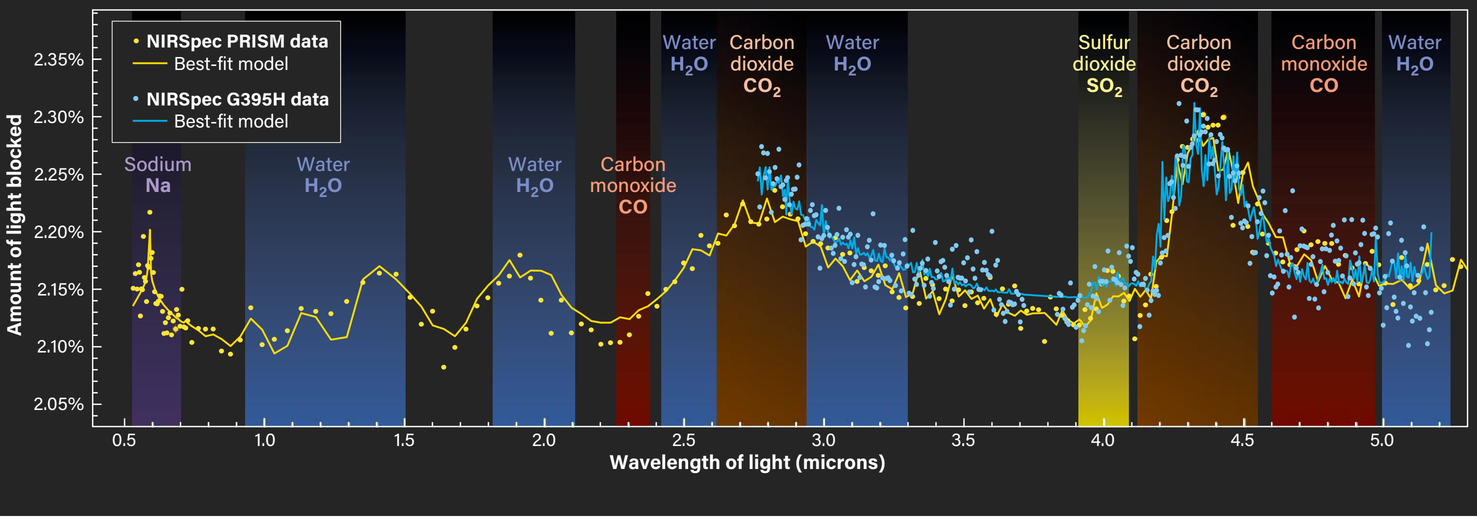
After conducting an exhaustive search of known molecular features, they honed in on a candidate: sulfur dioxide (SO_2), a molecule never before seen in an exoplanet spectrum. The JWST observations were a match to lab work and calculations by molecular spectroscopists. But to be



HOW TRANSMISSION SPECTROSCOPY WORKS

Transmission spectroscopy is possible when a planet with an atmosphere crosses in front of its host star. As the planet transits the star’s disk, a small fraction of the star’s light passes through the thin layer of atmosphere surrounding the planet before reaching us. The atmospheric molecules absorb some of that light. Analyzing which wavelengths have been absorbed can reveal which gases are present. ASTRONOMY: ROEN KELLY

THE TRANSMISSION SPECTRUM OF WASP-39 B



The James Webb Space Telescope observed a transit of WASP-39 b using multiple instruments and modes. Shown here are spectra taken by its Near Infrared Spectrograph (NIRSpec) operating in two different modes — one using a diffraction grating and another using a prism. Both spectra show the presence of water, sulfur dioxide (SO_2), carbon dioxide (CO_2), and carbon monoxide (CO); the prism, which covers a broader range of wavelengths, also reveals sodium (Na). *ASTRONOMY*: ROEN KELLY AFTER LUEBER ET AL. DOI: 10.1051/0004-6361/202348802 (CC BY 4.0)

confident of their detection, the team had to revisit their models and determine whether it made sense for sulfur dioxide to exist in WASP-39 b's atmosphere. These models take into account characteristics of an exoplanet like its temperature, pressure, and chemical composition.

But it turned out they were missing a key process: High-energy ultraviolet photons streaming from the WASP-39 host star can break apart water molecules — similar to how sunlight splits oxygen molecules in Earth's atmosphere to help form the ozone layer. On WASP-39 b, this initiates a series of reactions that could indeed produce sulfur dioxide — and in quantities large enough to explain the spectral feature detected by JWST.

Identifying a gas in an exoplanet atmosphere resulting from complex photochemistry and verifying its plausibility with models "was a spectacular achievement," says Bean. "The prediction of SO_2 required a lot of different pieces of information from different directions."

In many ways, it also highlights the process that researchers would follow if they were to identify gases that might indicate life.

Strange worlds

To find such gases, researchers are interested in rocky, Earth-sized exoplanets that lie in their host stars' habitable zones. Though no such planets have yet been detected around Sun-like stars, some have been found orbiting less luminous stars called M dwarfs.

These planets have several observational advantages. They orbit very close to their stars, in some cases completing one round trip in one or two days, allowing for more frequent observations to search for atmospheres. And because their stars are smaller and cooler, any life-indicating gases will absorb a higher fraction of their star's light and have a better chance of showing up in JWST's infrared spectra.

Researchers have already pointed JWST at the two innermost planets orbiting the M dwarf known as TRAPPIST-1. These planets, designated b and c, lie too close to be inside the habitable zone and are too hot for liquid water — but their quick orbits make them low-hanging fruit to see if they have atmospheres.

In addition to transits, JWST has also observed secondary eclipses, when a planet disappears behind its host star. Astronomers can search for signs of an atmosphere by measuring the heat from a planet's warm dayside just before and after the eclipse. But so far, they have come up empty-handed.

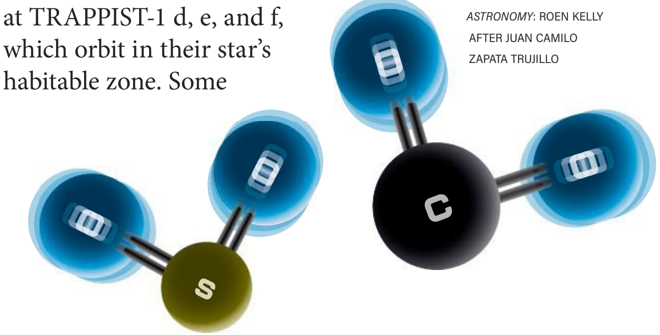
This may be because M-dwarf stars are extremely active, erupting with bouts of high-energy particles and radiation that can erode planetary atmospheres. M dwarfs are "very exciting systems," says planetary scientist Eliza Kempton of the University of Maryland, "but they're maybe not the most hospitable stars to put planets around."

The early results have some astronomers wondering whether rocky planets around these stars are capable of holding on to their original atmospheres, made of gases that they accreted when they formed. If they are, it seems they must orbit farther out.

In the next couple of years, astronomers plan to aim JWST at TRAPPIST-1 d, e, and f, which orbit in their star's habitable zone. Some

VIBRATING MOLECULES

The structures of molecules like carbon dioxide (CO_2) and sulfur dioxide (SO_2) can vibrate, absorbing light of certain wavelengths that match its natural vibrational frequencies and its overtones. *ASTRONOMY*: ROEN KELLY AFTER JUAN CAMILO ZAPATA TRUJILLO

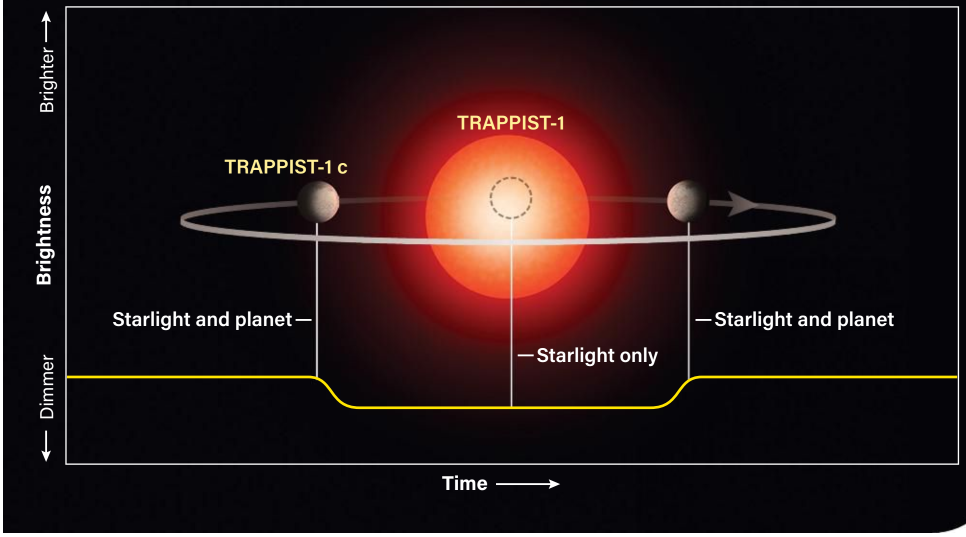


HUNTING FOR ATMOSPHERES

An increasingly important set of techniques to study exoplanet atmospheres involves taking observations when a planet slips behind its host star — an event called a secondary eclipse. Just before and after the star eclipses the planet, the planet shows its warm dayside to our vantage point. Although JWST cannot resolve the disk of the planet, scientists can subtract the light from the star alone — when the planet is behind it — to isolate and measure the infrared light that the planet emits from its dayside. If the planet has no atmosphere, the dayside will be scorching hot; but an atmosphere will circulate some of the heat around to the nightside, cooling the dayside.

For this technique, JWST observes in the 15-micron band, which is absorbed by carbon dioxide. By comparing observations to models of predicted spectra with and without atmospheres, researchers can gain insight into whether an atmosphere is present and, if so, what it is made of.

JWST's operator, the Space Telescope Science Institute in Baltimore, Maryland, has set aside 500 hours of director's discretionary time to search for atmospheres around rocky planets in more than a dozen nearby M-dwarf systems with this technique. The Hubble Space Telescope will assist by monitoring the host stars' activity. Scientists hope this initiative, called the Rocky Worlds DDT Program, will settle the question of whether Earth-sized worlds around M dwarfs can hang onto their atmospheres. *ASTRONOMY*: ROEN KELLY AFTER NASA, ESA, CSA, JOSEPH OLMSTED (STSCI); SCIENCE: SEBASTIAN ZIEBA (MPIA), LAURA KREIDBERG (MPIA)



models show there's a chance that TRAPPIST-1 d — on the inner edge of its star's habitable zone — has liquid water on its surface. As for the next two planets outward, "I think there's a chance that [e and f] could have nitrogen-dominated atmospheres like Earth's," says planetary scientist Howard Chen of the Florida Institute of Technology.

Researchers are also intrigued by the potential for life on other classes of exoplanets that have sizes in between Earth and Neptune. Known as super-Earths and mini-Neptunes, they are the most common types of exoplanet discovered to date.

Yet, there are no known examples in our solar system, leaving scientists unclear as to their true nature. "Is it just as simple as taking Earth and making it bigger or making Neptune smaller, or is there more going on here and are these objects entirely new or different?" asks Kempton.

The evidence so far is intriguing. Super-Earths have densities similar to our planet, suggesting they are rocky bodies. Mini-Neptunes have lower densities, which would seem to imply they are ice-covered and swaddled in a thick atmosphere of hydrogen and helium. But according to some models, a hydrogen atmosphere could sustain a global water ocean. These theoretical planets have been dubbed "hycean" worlds — a portmanteau of hydrogen and ocean. "You could imagine microbial life persisting in the upper layers of this ocean," says astrobiologist Edward Schwieterman of the University of California, Riverside. And if that life interacts with the atmosphere, it could produce signatures that JWST could detect, he adds.

In April, a team led by astronomer Nikku Madhusudhan of the University of Cambridge, U.K., claimed to have found a signal in a JWST spectrum of the candidate hycean world K2-18 b. They attributed the purported signal to dimethyl sulfide or dimethyl disulfide, the former of which is produced by phytoplankton in Earth's oceans. But some scientists have expressed skepticism — including Schwieterman, who says he is not yet convinced that the current data are of sufficient quality to confirm the detection of these gases.

An ensemble act

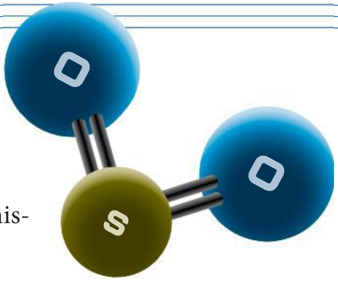
To assess the range of possible gases in exoplanet atmospheres that could be produced by life, scientists lean on what they know from Earth. For instance, oxygen is mainly produced by photosynthesis, and metabolizing microbes release most of the methane and nitrous oxide present. But proving from afar that these gases are the result of life — and not some other nonliving process — is not simple. For example, carbon dioxide and methane (CH_4) can be produced by volcanic outgassing.

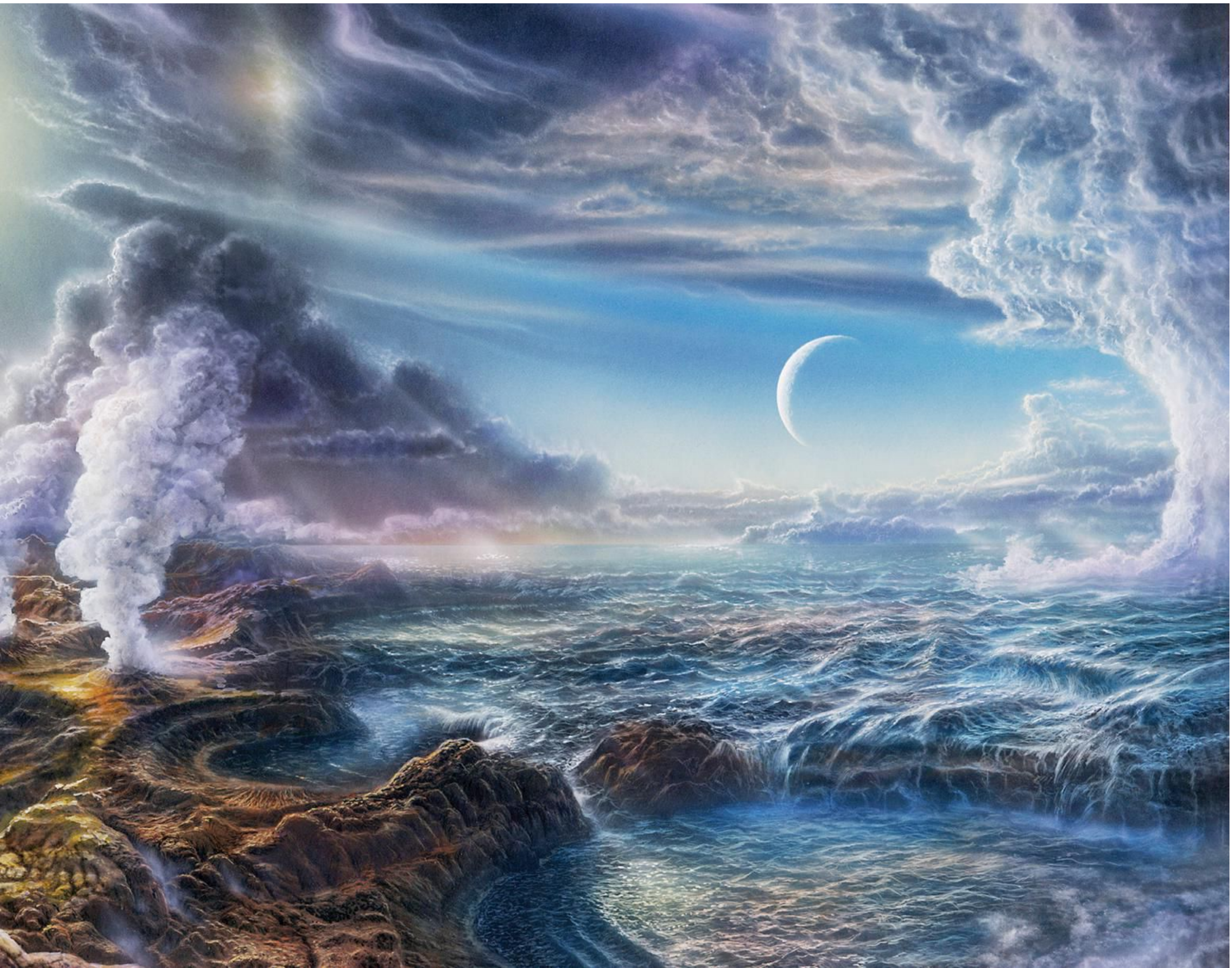
Therefore, researchers are looking to identify combinations of gases in exoplanet atmospheres that could strengthen the case that life is producing them. “Really, it’s about looking for gases that shouldn’t be there at high abundances,” says Schwieterman.

For example, finding methane and carbon dioxide in a rocky exoplanet atmosphere would be appealing because the former is readily converted to carbon dioxide by reactions with light if not continually replenished — perhaps by life. This pair would be even more appealing if accompanied by an absence of carbon monoxide, which is consumed by organisms for energy. “It’s very hard to get those two species and no carbon monoxide through abiotic sources,” says planetary scientist Maggie Thompson of the Carnegie Institution for Science in Washington, D.C., and ETH Zurich in Switzerland.

A rocky methane-rich planet would also be reminiscent of early Earth, when microbes produced thousands of times more methane than present in our atmosphere today. “It would be interesting if life evolves on other planets in a similar way to how it evolved on Earth,” says Thompson.

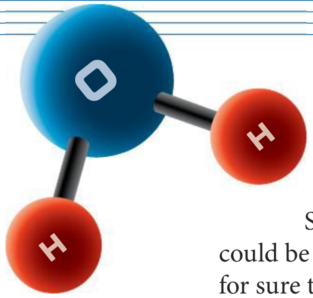
Another way to boost the case that a potential biosignature is caused by life is to see if it changes seasonally. On Earth, the abundances of gases like methane and carbon dioxide vary as plants grow and fade with the changing amount of solar radiation. “It





Early Earth’s atmosphere was filled with methane produced by microbes called methanogens. If life frequently evolves in this fashion, methane could be a potential biosignature.

DON DIXON



wouldn't be the first thing you would look for because it's very hard to detect," says Schwieterman, "but it could be something that tells us for sure that there's life after you have already identified the planet as an interesting target."

There is also the possibility that exoplanet atmospheres host different forms of life. On Earth, for instance, elements essential for life are sourced from chemical reactions between predominantly silicate rocks and water. But that could change if the mineralogy is different, says Thompson.

And life could be based on solvents other than water, like methane or ethane. "We definitely need to be able to recognize things that are like Earth," says Schwieterman, "but life could take on different characteristics."

Future directions

The current cycle of JWST observations includes a program focusing on observing secondary eclipses of rocky exoplanets around M dwarfs. Researchers aim to gather enough data to get a good sense of whether such planets can retain atmospheres at all.

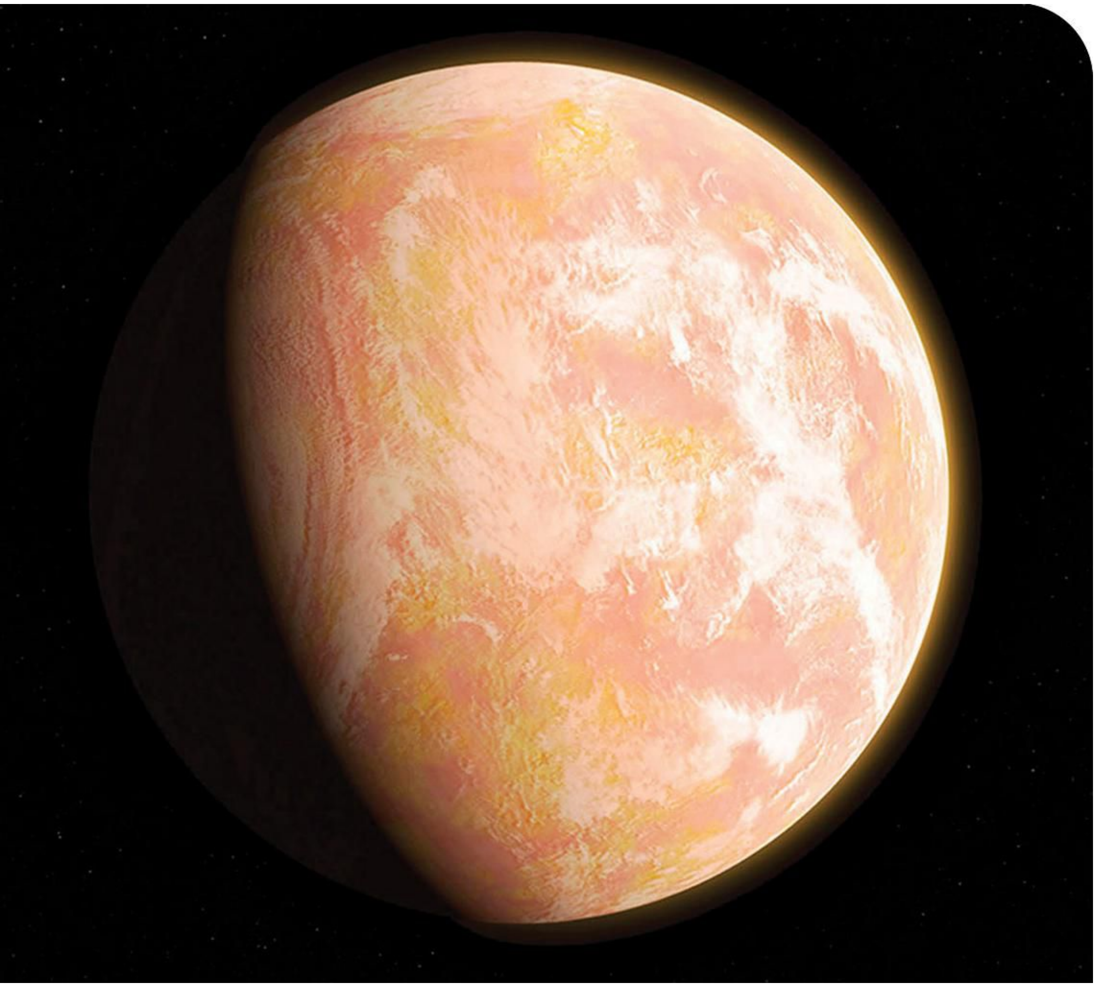
If one or more planets are found to host atmospheres, scientists will likely plan additional observations, combining data and searching for spectral signatures. Up to 200 hours of stacked observations may be necessary to be confident any features are potential signs of life and not due to instrument noise or variations in their stars' outputs. "As the years go by, we will start pushing the limits of the sensitivity of the telescope and really doing the harder things," says astrophysicist Macarena Garcia Marin, the deputy project scientist in the Webb Mission Office at the Space Telescope Science Institute.

Then, starting in 2030, the European Southern Observatory's Extremely Large Telescope (ELT), currently under construction in Chile, will join the hunt. With a 39-meter primary mirror to JWST's 6.5-meter mirror, the ELT will surpass JWST's ability to resolve exoplanets directly and conduct high-resolution spectroscopy of their atmospheres. The ELT may even be capable of detecting the most suggestive ensemble of biosignatures — the pairing of oxygen and methane — in the atmospheres of rocky planets around M-dwarfs.

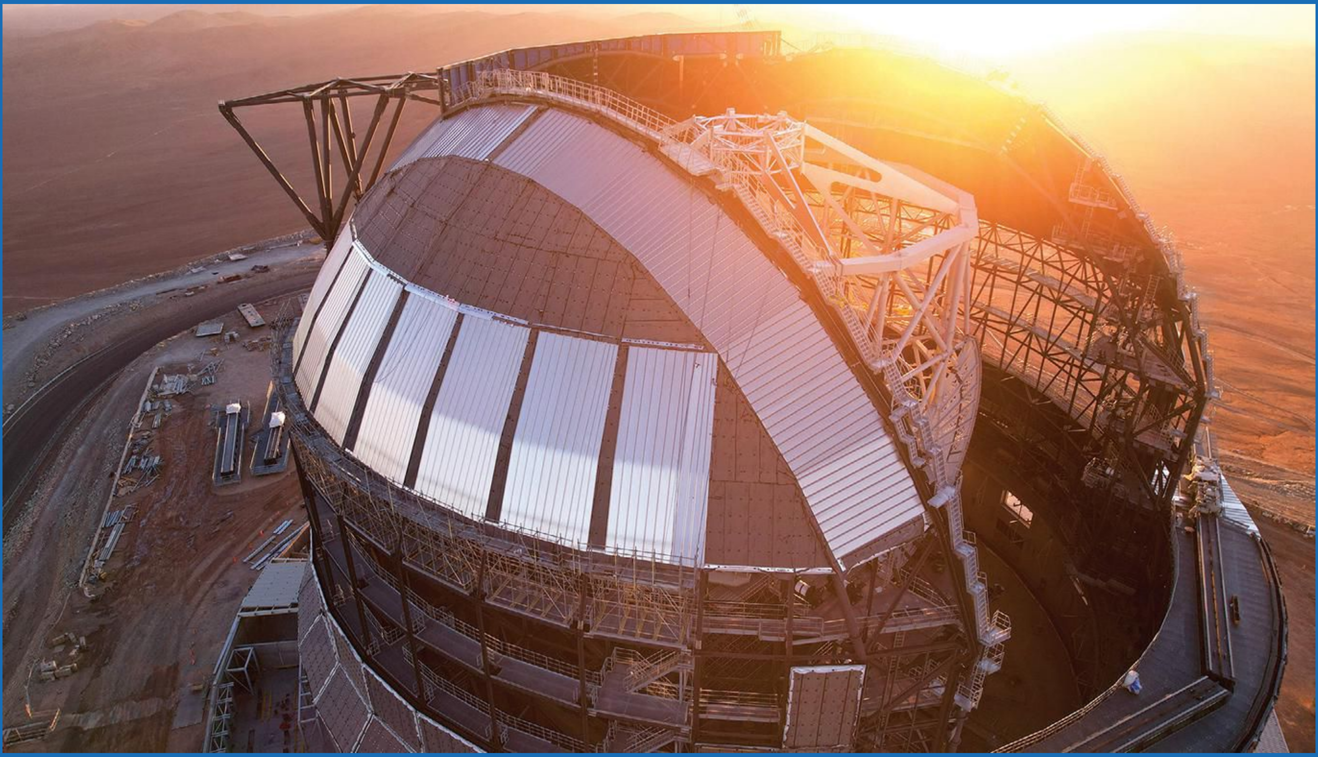
Scientists are also looking forward to NASA's next flagship observatory in planning — the Habitable Worlds Observatory, expected to launch in the 2040s. The telescope will be powerful enough to directly image habitable exoplanets, analyzing the starlight they reflect. It is being designed to detect oxygen and other potential biosignatures in planetary atmospheres. "I think we're going to be able to look at systems that are much like our solar system and have true Earth twins," says Chen.

As these facilities come online, spectral features that don't correspond to known vibrational frequencies will likely appear. "This is a problem we're going to start seeing more and more as we gather more data from telescopes," says computational spectroscopist Juan Camilo Zapata Trujillo. That means molecular spectroscopists will need to conduct time-intensive lab experiments.

One complementary approach



The atmosphere of early Earth featured heavy clouds and hazes, as shown in this artist's depiction. Such hazes are also expected to be present in cooler exoplanet atmospheres, which would scatter infrared light and make spectral peaks broader and less distinct. Scientists are trying to develop models that could decipher faint signals within such spectral bands. NASA'S GODDARD SPACE FLIGHT CENTER/FRANCIS REDDY



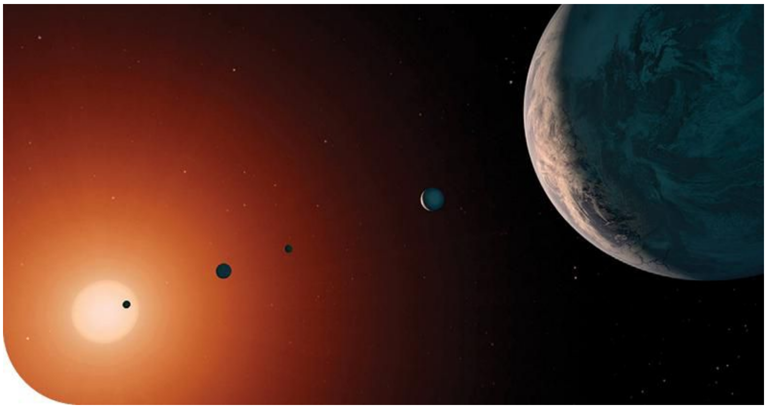
ESO/G. VECCHIA

EUROPE'S STAR POWER

The European Southern Observatory's 39-meter Extremely Large Telescope, pictured here under construction in Chile in January 2025, is more than halfway complete. When it begins operations — scheduled for 2030 — it will be the largest optical telescope in the world, with an ability to resolve and directly image exoplanets that surpasses that of the James Webb Space Telescope.

The U.S. is funding two telescopes of comparable size — the Giant Magellan Telescope in Chile and the Thirty Meter Telescope (TMT) atop Maunakea in Hawaii. But amid rising costs and budget uncertainty, in 2024, the board of the National Science Foundation (NSF) recommended cutting its support for one of them.

For now, both scopes remain in limbo. A December 2024 report commissioned by NSF did not recommend either facility for advancement to the final design phase, nor did it recommend which one to cut. The report also acknowledged that the future of TMT hinges on the approval of local and Native Hawaiian communities.



TRAPPIST-1 f lies in the foreground of this artist's rendering of the TRAPPIST-1 planetary system.
NASA/JPL-CALTECH

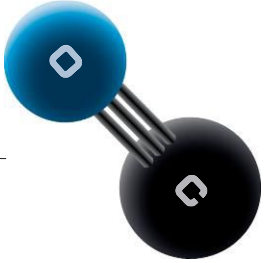
that Zapata Trujillo worked on during his Ph.D. at the University of New South Wales in Sydney is using computational quantum chemistry to produce approximate vibrational frequencies for thousands of molecules.

This approach has already borne fruit. For example, his approximations were able to narrow down an unknown 4.5-micron signal in JWST's spectrum of WASP-39 b to a stretching of carbon-nitrogen bonds in one of three molecules. "It's easier to run calculations or take measurements for three or 10 molecules instead of 1,000," says Zapata Trujillo.

The more gases that scientists can identify in an exoplanet's atmosphere, the better they will understand how that planet formed and evolved, helping to assess the likelihood that any detected spectral features are biosignatures.

Humans have long wondered about the possibility of life outside the solar system. That scientists have the ability to probe that question is in large part to strengthening bonds between observatories and laboratories. And it is a development that amazes even the scientists who are working on it, like Kempton. "It's an absolute marvel that we are able to disentangle signatures of planetary atmospheres from those burning, bright stars in the sky," she says.

Theo Nicitopoulos *is a science writer who covers Earth and space science.*



DID EARTH ONCE

Long before the dinosaurs, our planet may have looked a little like Saturn.

BY ASHLEY BALZER VIGIL

Amid the cold silence of the main belt, a giant rock drifts through space. It has existed for billions of years unchanged, but today, it will be irrevocably broken.

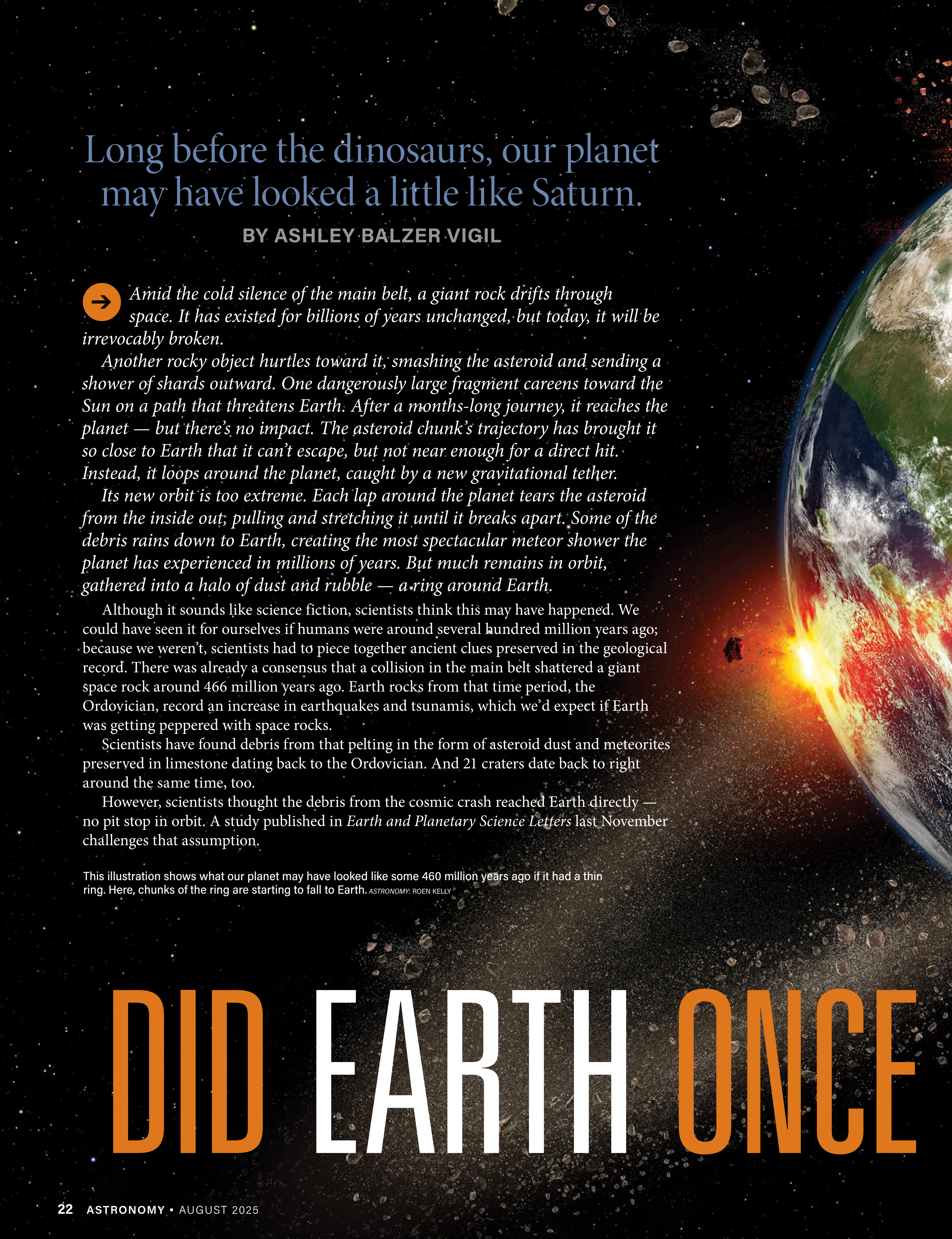
Another rocky object hurtles toward it, smashing the asteroid and sending a shower of shards outward. One dangerously large fragment careens toward the Sun on a path that threatens Earth. After a months-long journey, it reaches the planet — but there's no impact. The asteroid chunk's trajectory has brought it so close to Earth that it can't escape, but not near enough for a direct hit. Instead, it loops around the planet, caught by a new gravitational tether.

Its new orbit is too extreme. Each lap around the planet tears the asteroid from the inside out, pulling and stretching it until it breaks apart. Some of the debris rains down to Earth, creating the most spectacular meteor shower the planet has experienced in millions of years. But much remains in orbit, gathered into a halo of dust and rubble — a ring around Earth.

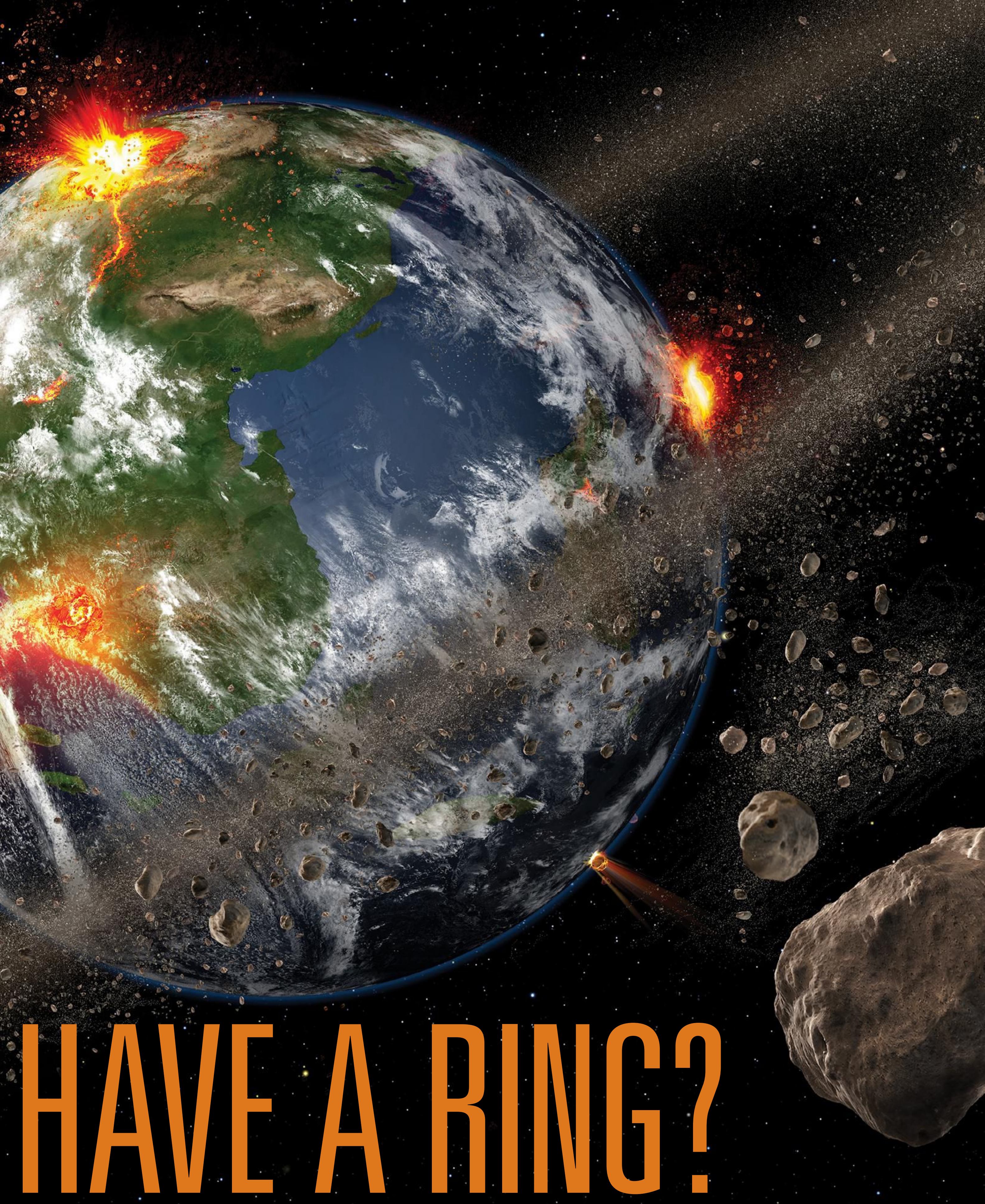
Although it sounds like science fiction, scientists think this may have happened. We could have seen it for ourselves if humans were around several hundred million years ago; because we weren't, scientists had to piece together ancient clues preserved in the geological record. There was already a consensus that a collision in the main belt shattered a giant space rock around 466 million years ago. Earth rocks from that time period, the Ordovician, record an increase in earthquakes and tsunamis, which we'd expect if Earth was getting peppered with space rocks.

Scientists have found debris from that pelting in the form of asteroid dust and meteorites preserved in limestone dating back to the Ordovician. And 21 craters date back to right around the same time, too.

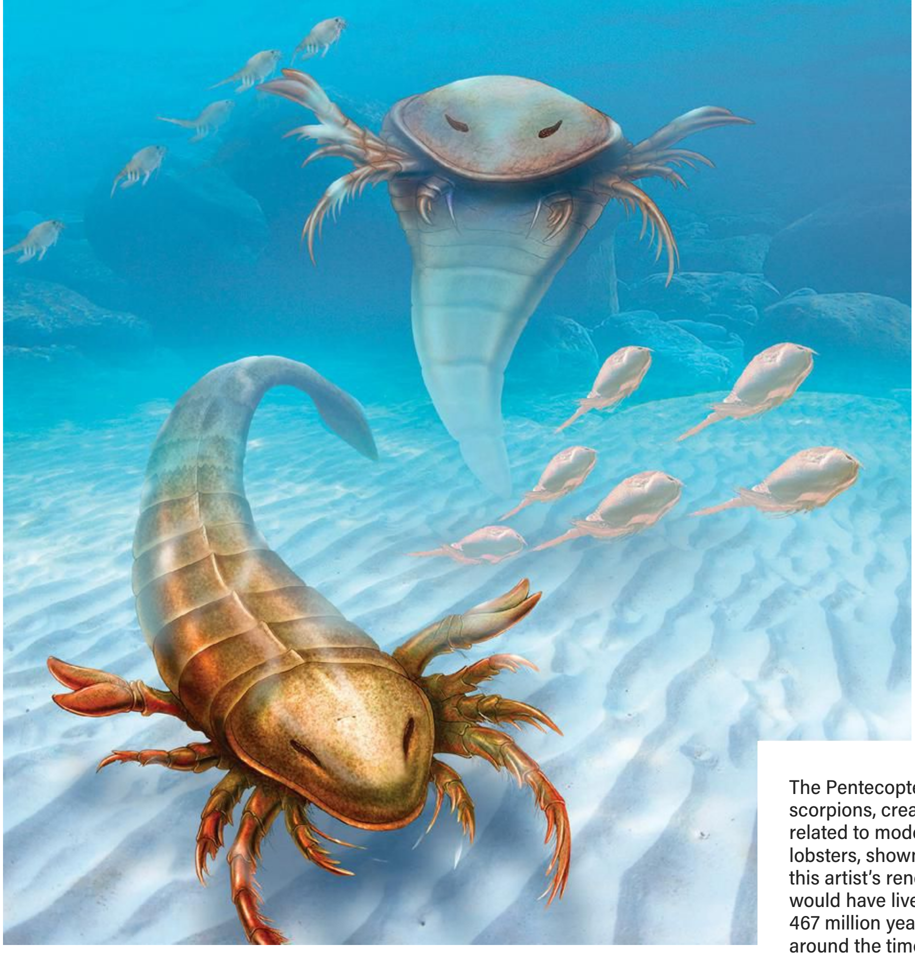
However, scientists thought the debris from the cosmic crash reached Earth directly — no pit stop in orbit. A study published in *Earth and Planetary Science Letters* last November challenges that assumption.



This illustration shows what our planet may have looked like some 460 million years ago if it had a thin ring. Here, chunks of the ring are starting to fall to Earth. *ASTRONOMY*: ROEN KELLY



HAVE A RING?



The Pentecopterus sea scorpions, creatures related to modern lobsters, shown in this artist's rendering would have lived some 467 million years ago, around the time researchers think Earth had a ring. PATRICK LYNCH/ WIKIMEDIA COMMONS

Forensic planetology

After reading about how Mars' moons may have formed from material in a ring, Andy Tomkins, professor of earth and planetary sciences at Monash University in Australia, wondered how we might be able to tell whether Earth once had a ring, too.

"Ring formation is a relatively common thing," Tomkins says. "Mars may have had one, all the outer planets have them. Why not Earth?" And if Earth did have a ring in the past, Tomkins wondered, how would we know?

The surge of tsunamis and earthquakes, surplus meteorite debris (100 to 1,000 times more than usual), and so many craters during the Ordovician all signal that something major happened then.

"It's just a question of what it was," Tomkins says. Space rocks do strike Earth periodically and sometimes leave craters, but it would typically take tens or even hundreds of millions of years to accumulate 21 of them. Scientists think the Ordovician craters all formed within a period of thousands to hundreds of thousands of years.

The combination was suspicious enough to warrant a closer look. Tomkins reasoned that the craters could have been made by material that fell from a ring. If that were true, their locations should indicate they came from a restricted region above the planet. The trouble is that over the intervening 466 million years, plate tectonics have shifted the craters around the planet.

Careful studies enable scientists to essentially rewind continental drift. Tomkins and his team used plate tectonic reconstructions to see where the 21 craters from the Ordovician meteor event were when they were created. If they were made by asteroid fragments that smashed directly into Earth, the craters should be randomly distributed all over the globe.

But if they were created by a fallen ring, they should be concentrated near the equator. Orbiting debris would be drawn into an equatorial orbit by Earth's gravitational field and rotation. The material would stabilize there, the way the rings around the outer planets encircle their equators.

Over time, pieces of the ring would fall as their orbits decayed. Their trajectory would send them near the planet's midsection, with larger chunks leaving craters. Tomkins and his team found that all 21 craters from the Ordovician meteor event were originally within about 30° of the equator — the middle third of the planet.

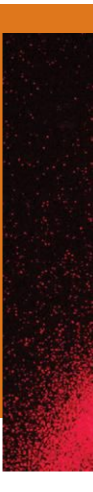
Phil Plait, an astronomer who was not involved in the study, says that while this isn't ironclad proof of a collapsed ring, it's strong evidence. "Statistically

CRACKING UNDER PRESSURE

The world saw an object disintegrate due to tidal forces in the early 1990s, when Comet Shoemaker-Levy 9 was torn apart upon close approach to Jupiter. Not quite spaghettified, the comet was broken into a "string of pearls" that impacted Jupiter within a couple years of its discovery, marking the first time anyone had ever witnessed an object impacting a planet.

The comet's original path around the Sun brought it close enough to Jupiter that its gravitational allegiances changed, and it began orbiting the giant world instead. But its new orbit was unstable and brought it too close to the planet (within the Roche limit), and tidal forces were too strong for the comet to hold itself together. After it crumbled into pieces, it continued in a gradually decaying orbit before finally raining down onto the planet in 1994.

Scientists think the same phenomenon may have created the outer planets' rings when moons were crushed under the pressure of tidal forces (although some could have been shattered by impacts with other objects). Those rings have lasted a long time — estimates range from millions to billions of years — but they, too, have an expiration date. Eventually gravity will pull the orbiting dust and rocks down to their parent planets' surfaces, and the rings will dissipate unless they're replenished by new material. *—A.B.V.*



Comet Shoemaker-Levy 9 broke into 21 fragments and fell into Jupiter's atmosphere in July 1994. The evidence of those impacts, however, quickly vanished. H. A. WEAVER/T. E. SMITH/STSCI/NASA/ESA speaking, only about 30 percent of Earth's surface within 30° of the equator was covered by land at the time the ring is presumed to have existed, so it's unlikely this would occur by chance," he says.

Breaking point

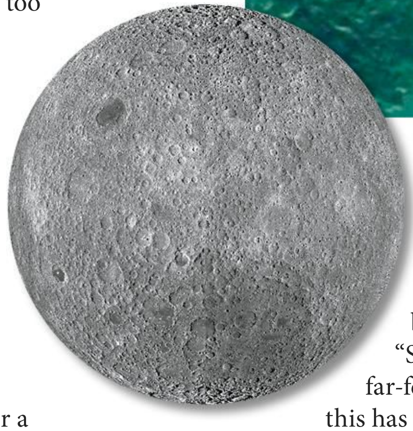
The scientists who conducted the study say the asteroid fragment that would ultimately create Earth's ring ventured too close to the planet, past a point called the Roche limit beyond which the asteroid simply couldn't remain intact.

"You may have heard of the term spaghettification, which is used to describe an object getting stretched and ripped apart as it gets too close to a black hole," Tomkins says. "The same sort of principle applies when a body like an asteroid passes too close to a planet." The only difference is the degree of stretching and tearing, which is lower because the gravity is less extreme than near a black hole.

When a small object that's loosely held together experiences tidal stretching from a close encounter with a planet, the effect can break the object into a stream of fragments. That's likely what happened to the asteroid fragment as it approached Earth.

The fragment had to pass through an extremely narrow region of space to be shredded by Earth's gravity. "But over time — billions of years — close passes by asteroids, even decent-sized ones, are inevitable," Plait says. "So it's not too far-fetched to think this has happened at least once in Earth's history."

ABOVE: The Pilot Lake impact crater in Canada's Northwest Territories is one site some researchers think formed when pieces of Earth's ring fell to Earth. It measures 3.7 miles (6 km) across. USGS/NASA LANDSAT PROGRAM



LEFT: The lunar farside retains many scars from meteorite bombardments. Scientists are searching for evidence of a similar, large-scale event on Earth that may have happened when our planet's ring fell. NASA/GSFC/ARIZONA STATE UNIV.

There could have been several prior renditions earlier in the planet's history. While those may be mostly unknowable due to a geological record that weakens with age, Tomkins still thinks the ring from 466 million years ago was at least Earth's second. Most theories about the Moon's formation explain that it was created following a collision between Earth and a Mars-sized body, as debris from the crash coalesced in orbit from a short-lived ring.

Although the asteroid that was ripped apart near Earth 466 million years ago was likely just one piece of a larger body from the main belt, it was probably still a significant size — perhaps just larger than the one that wiped out the dinosaurs some 66 million years ago. Had it been on a slightly different trajectory, the outcome could have been quite different.

Life on Earth was still mainly confined to the ocean 466 million years ago. There were some land plants back then, but according to fossil records, land animals wouldn't evolve for a few dozen million more years.

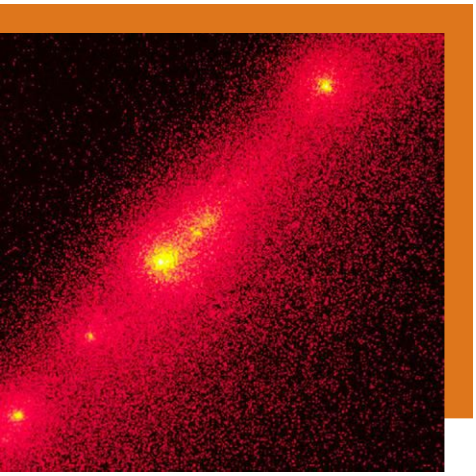
A direct impact by the asteroid fragment probably wouldn't have caused the same degree of mass extinction as the later dino-killing impact, since the effects are more extreme on land than underwater. But there's reason to think the formation of a ring may have dramatically altered the course of life on Earth.

Cold case

Earth's ring likely persisted for millions of years, perhaps as a faint, dusty band arcing across the sky during the day and subtly glowing at night. It may not have directly caught the attention of the trilobites, corals, and early ancestors of animals like squid that inhabited the planet back then. But the ring would have cast shade on Earth, blocking sunlight like a visor and cooling the planet.

"You can see how Saturn's rings cast a shadow on the planet," Tomkins says. "The same sort of thing would have happened on a smaller degree, since this ring for Earth would have been smaller."

Thanks once again to ancient rocks,



WHY DO THE OUTER PLANETS ALL HAVE RINGS?

The most famous ring system is the one that circles Saturn. Most astronomers think it formed 4 billion years ago, but recent evidence from the Cassini spacecraft has others thinking it may be only a few hundred million years old. Scientists think that between 100 million and 300 million years from now, the rings' particles will all fall into Saturn. NASA/JPL/SPACE SCIENCE INSTITUTE

TO MAKE A RING, you need material and opportunity. The outer regions of our solar system are rich with both.

"You know how many moons the outer planets have — totaling in the hundreds, compared with only three for the terrestrial planets," Tomkins says. "That's a clue."

Farther from the Sun, in the main belt and especially the Kuiper Belt beyond Neptune, it was cold enough for lots of small, icy objects to form. That means there are more potentially ring-forming objects around, and greater chances for something to drift close enough to a planet to break apart. —*A.B.V.*

scientists have studied the ratios of isotopes in marine sediments, which act like natural thermometers. (Isotopes are different "flavors" of the same element; they're atoms that contain the same number of protons but a different number of neutrons in their nuclei.) Studying these records of past water temperature indicates that there was a strange supercooling that roughly coincides with the time of the ring's formation.

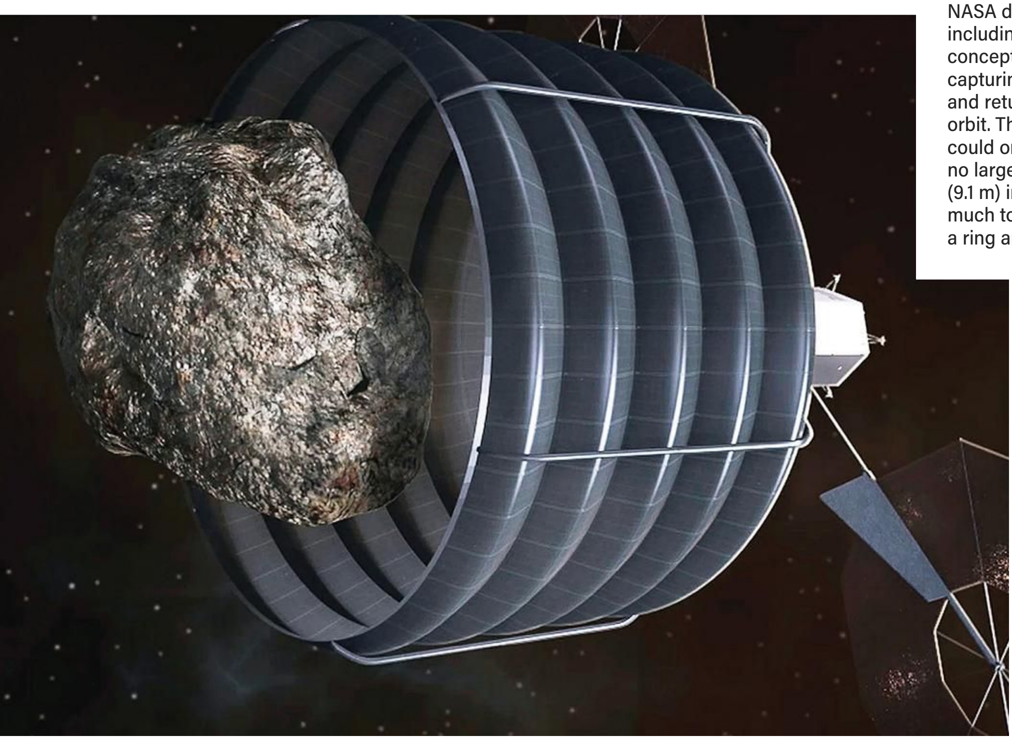
When Earth's surface temperature plunged, parts of the planet you wouldn't expect to be frozen became ice-encrusted (as indicated by glacial deposits), and sea levels fell rapidly. The weirdest part is this ice age actually occurred during a time when an abundance of carbon dioxide in the atmosphere should have caused our planet to warm.

Scientists have suggested several possible explanations for this freeze, ranging from continental drift to weakened solar activity. But perhaps a crown of cosmic rubble played a role in lowering Earth's temperature so severely and abruptly. While marine animals probably would have been at least somewhat insulated from a direct asteroid impact, they couldn't escape the effects of a cooling planet. So in this case, by not striking Earth, the asteroid likely caused a lot more deaths than if it had.

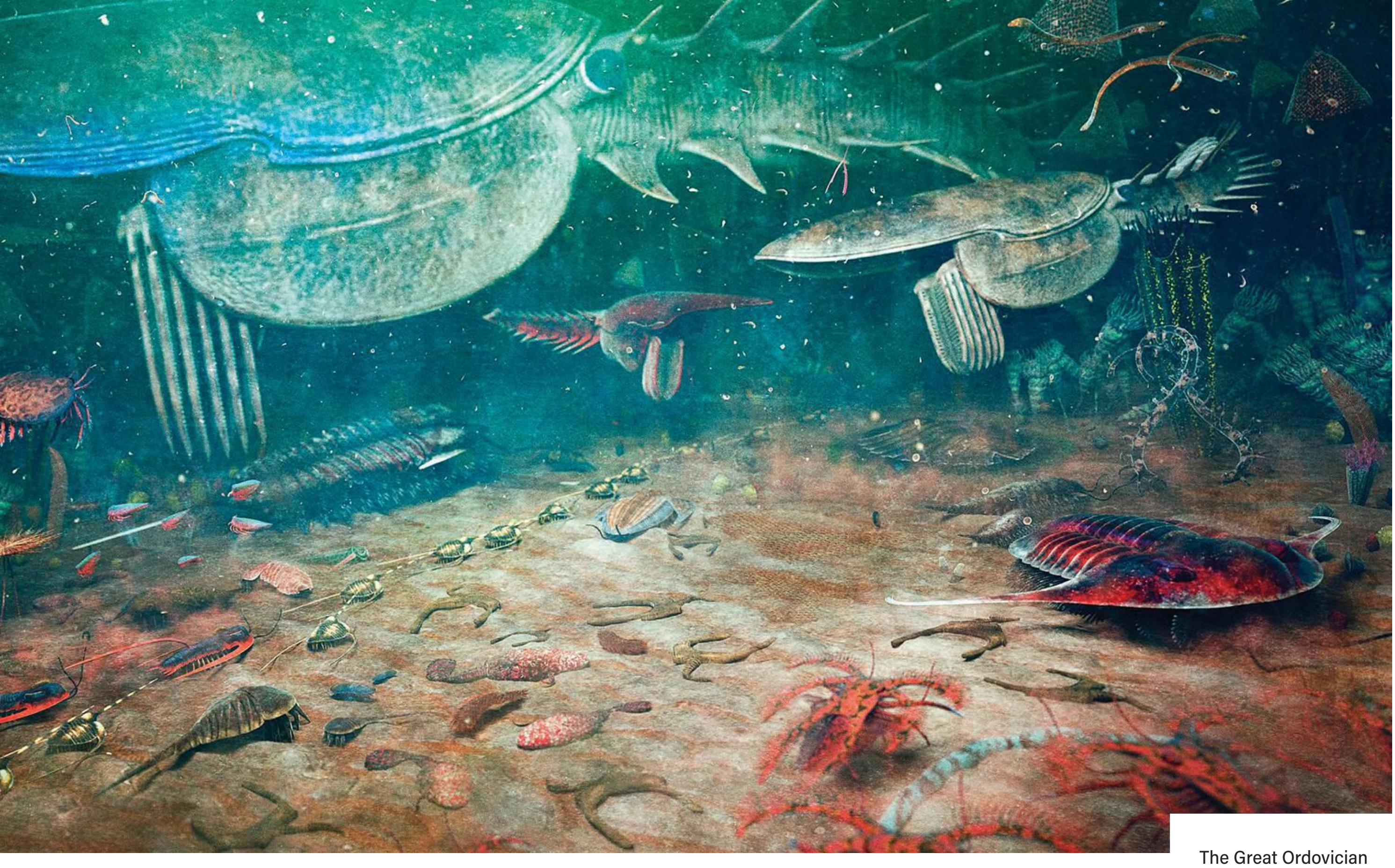
Fossil records show that around 445 million to 443 million years ago, three-fourths of animal life was wiped out, unable to survive the chillier temperatures. That's around the time of another major temperature shift. From about 444 million to 437 million years ago, Earth rapidly warmed up again — perhaps as the ring dissipated and the cooling effects caused by it lifted.

Somewhat counterintuitively, the same big change in Earth's temperature may have been a boon to life as well. The Great Ordovician Biodiversification Event occurred around the same time the ring is thought to have formed. During this pivotal period, many new types of life arose as some species were able to adapt to the altered conditions or move into different environments.

Many ancestors of the life-forms we see today appeared during this time, laying the foundation for modern marine ecosystems. And increased complexity of ocean ecosystems helped stabilize the planet's biogeochemical cycles, which



NASA drew up plans, including this artist's conception, for capturing an asteroid and returning it to Earth orbit. The spacecraft could only retrieve one no larger than 30 feet (9.1 m) in diameter, much too small to form a ring around Earth. NASA



The Great Ordovician Biodiversification Event occurred around the time researchers believe Earth had a ring. Many new life-forms developed, either by adapting to the new climate or by moving to more favorable environments. PALEOEQUII/WIKIMEDIA COMMONS

> “We still don’t know a lot about Earth’s deep past, and allowing our imaginations to explore unusual paths is a good way to open up more exploration of the topic.”

helped pave the way for terrestrial life to thrive. So while Earth’s ring was temporary, it may have had substantial, lasting effects on life on Earth.

Re-ringing Earth

A chance encounter with an asteroid that led to the creation of a ring around Earth that cooled the planet and supercharged evolution — it sounds wild. But rings are commonplace. They may be a one-in-several-million result, but the solar system has been around for 4.6 billion years.

“I’d say this wasn’t the first time Earth had a ring and won’t be the last, most likely,” Tomkins says.

Some might even feel tempted to give a small asteroid a nudge in our direction. If its trajectory were precise enough, it would break apart and potentially create a new ring around the planet. Goodbye, global warming!

“The problem — besides the cost of finding and towing an asteroid into Earth orbit, which is a lot — is that we don’t know what all the effects would be,” Plait says. “Changing the climate globally almost overnight could cause a lot of instability in our ecosphere that could add to the damage we’re already doing.” Not to mention the possibility of accidentally sending the asteroid crashing into Earth. Plus, global warming is a human-made problem we should be capable of solving, so we should keep working on that “before trying out an untested experiment on our entire planet,” Plait says.

Scientists aren’t even entirely sure about the effects a ring 466 million years ago may have had on the planet, or whether the ring existed for certain in the first place.

But, Plait says, “Even if it turns out to be wrong, I love hypotheses like this. We still don’t know a lot about Earth’s deep past, and allowing our imaginations to explore unusual paths is a good way to open up more exploration of the topic, inspire more ideas. If it’s correct then it provides a direction for us to pursue more research, and if not, well, disproving something is valuable as well because it means there’s a different reason for the observations we’re making.”

Cosmic questions sometimes feel far removed from earthly affairs, a distinctly separate category. But studying them helps us understand how Earth’s environment has shaped its formation, climate, and even perhaps the course of the evolution of life.

Research drives technological innovations and scientific awareness. Working together they can help us better protect and sustain life on Earth, and perhaps someday, elsewhere too.

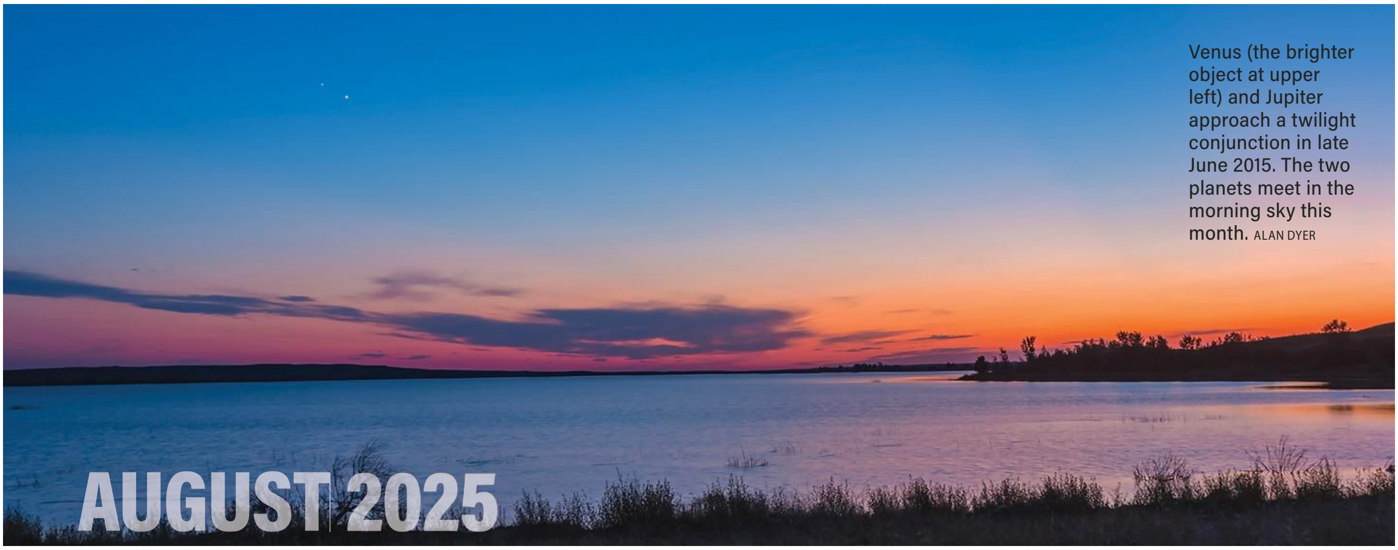
Ashley Balzer Vigil *is a NASA science writer and freelancer with master’s degrees in space studies and science writing.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING



Venus (the brighter object at upper left) and Jupiter approach a twilight conjunction in late June 2015. The two planets meet in the morning sky this month. ALAN DYER

A month of close meetings

» The longer nights of August beckon with several treats this month. Saturn and Neptune undergo their second conjunction of the year, appearing together in a low-power telescope eyepiece. Telescopic observers also get two shadow transits of Titan across Saturn. Early risers enjoy a spectacular conjunction of the two brightest planets in the sky, Venus and Jupiter, on Aug. 12, the same day the Perseid meteor shower peaks.

Mars glows at magnitude 1.6, low in the western sky after sunset. Throughout August it travels across southwestern Virgo. On Aug. 2, the Red Planet stands 8' southeast of 4th-magnitude Beta (β) Virginis. Look for the pair 10° high in the western sky an hour after sunset.

Mars then moves to sit 2.7° south of Porrima (Gamma [γ] Virginis) on the 24th. On that date, Mars is also 13° to the lower right of 1st-magnitude Spica, Virgo's brightest star.

A fine crescent Moon is visible soon after sunset on the 25th, with Mars 7° to its upper left (east). The next evening, the Moon, Mars, and Spica form a skewed triangle, with Spica 7° east of the Moon.

Through a telescope, it is difficult to see any detail on the small, 5"-wide martian disk. While Mars remains visible in the evening sky for months, the telescopic view doesn't improve.

Saturn and **Neptune** rise together around 10:30 P.M. local daylight time on Aug. 1. Saturn starts the month at magnitude 0.8 and is an easy object low in the eastern sky an hour after it rises. Both planets lie in western Pisces, southeast of the Circlet.

Neptune and Saturn undergo the second of three conjunctions within the span of a year. The first occurred at the end of June; this month, they are 1.1° apart on Aug. 6. A third conjunction occurs Feb. 15, 2026, when they are 0.9° apart.

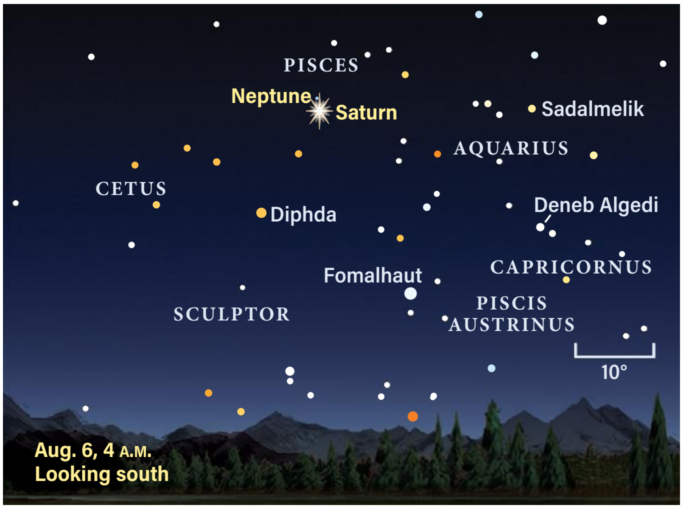
Neptune is magnitude 7.7, within reach of binoculars. It is fairly obvious due north of Saturn in a low-power eyepiece in a telescope.

Viewing both planets together is rare. Consider that Neptune lies 1.9 billion miles beyond Saturn! Saturn's disk appears 19" across, while bluish Neptune spans a mere 2".

We have a fine view of the southern face of Saturn's rings for the first time in over 15 years. The rings are tilted 3° to our line of sight. With the narrow rings, it's a good time to watch for any unusual bright cloud features on Saturn's disk.

Our Moon passes close by

Distant worlds meet



Saturn and Neptune undergo a conjunction Aug. 6. Neptune is only visible using a telescope or binoculars; both planets will appear together in a low-power telescope eyepiece. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

VENUS and **JUPITER** stand 0.9° apart the morning of Aug. 12 — the same day the Perseid meteor shower peaks.

overnight on Aug. 11/12. Soon before sunrise on the 12th, Saturn stands 3.5° southeast of Moon, while Neptune is 1.2° north of Saturn.

Titan, Saturn's largest moon, shines at magnitude 8.5. It's an easy object to spot in small telescopes. Due to the current tilt of its orbit, Titan's shadow transits Saturn's disk, with repeat events over the next few months.

The first event is lined up nicely for the U.S. and Canada. Titan's shadow begins a transit Aug. 3 at 2:04 A.M. EDT. It takes about 17 minutes for the shadow to fully appear. Local atmospheric conditions will affect how well you see ingress.

By about 4:30 A.M. EDT, the shadow sits midway across the disk. Titan itself is about 10" off the northeastern limb of Saturn. The shadow begins its egress from the northwestern limb around 5:12 A.M. MDT, after sunrise in the Midwest. Egress takes about 20 minutes.

A note for imagers: both Enceladus (magnitude 11.8) and Tethys (magnitude 10.3) are transiting the disk just north of the rings at the same time as Titan's shadow. Enceladus' transit begins around 2:10 A.M. EDT, followed by Tethys 23 minutes later. The pair crosses Saturn in about two and a half hours. They are challenging to see visually against the bright planet.

— Continued on page 34

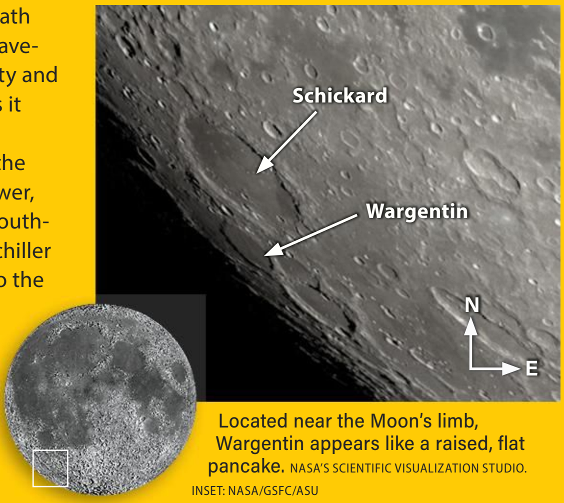
RISING MOON | Wargentin pancake

THE NEARLY FULL MOON of August sports its own filter. Never climbing higher than Antares, Luna's light must travel a longer path through Earth's atmosphere, losing blue wavelengths. Add in the haze from high humidity and it will be quite yellow. Wildfire smoke takes it into eclipselike orange.

On the night of the 6th, after taking in the magnificent ray system of Tycho at low power, grab a shorter eyepiece to zoom into the southwestern limb. The standout shoeprint of Schiller is one guidepost, while one step behind (to the west) lies the large, flat depression of Schickard. Immediately limbward lies the raised oval of Wargentin with a smooth, flat face, just like a pancake!

Astronomers surmise Wargentin began as a normal bowl-shaped crater. Much later, lava welled up through a cracked floor, filling it almost to the brim. Underground compression then forced up wrinkle ridges through the middle. The mild shadow indicates it is a long hill. Confirming its relative youth, the smooth surface is pocked only by two small craters that challenge a 6-inch scope and steady air.

Wargentin

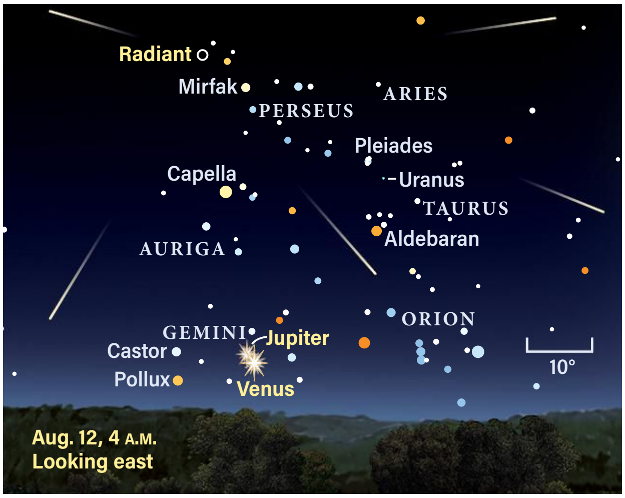


Located near the Moon's limb, Wargentin appears like a raised, flat pancake. NASA'S SCIENTIFIC VISUALIZATION STUDIO. INSET: NASA/GSFC/ASU

By the 7th, the Sun has risen higher in the lunar sky, wiping out the shadows. The best 3D views are found at the north pole of the Moon from four days before to four days after Full phase, as features cast shadows that seem to exaggerate the relief.

METEOR WATCH | A busy morning

Perseid meteor shower



The Perseids peak the morning of the conjunction between Venus and Jupiter. Uranus will likely require binoculars to view under the bright conditions.

A FULL MOON Aug. 9 significantly affects the visibility of Perseid meteors. By Aug. 12, the night of the Perseids' peak, the Moon rises around 10 P.M. local daylight time and remains up the rest of the night, just as the shower's radiant in Perseus is climbing higher in the sky.

But all is not lost — the Perseid meteor shower carries some of the brightest meteors, which are always visible even with moonlight. You can improve the visibility of fainter meteors by traveling to higher altitudes (above 5,000 feet), where a thinner atmosphere reduces the scattered light of the Moon, rendering the sky darker. Even so, observed rates this year will be well below the advertised peak. Set your expectations at a dozen per hour.

The Perseids are active from July 17 through Aug. 24. The earlier part of the shower occurs under a dark Moon. On Aug. 1, for example, the First Quarter Moon sets around midnight. The radiant reaches a respectable 50° in altitude by 4 A.M. local daylight time. The moonless skies diminish by nearly an hour each day.

The Perseids are associated with Comet 109P/Swift-Tuttle, which last reached perihelion in 1992 and returns again in a century.

PERSEID METEORS

Active dates: July 17–Aug. 24
Peak: Aug. 12
Moon at peak: Waning gibbous
Maximum rate at peak:
100 meteors/hour

STAR DOME

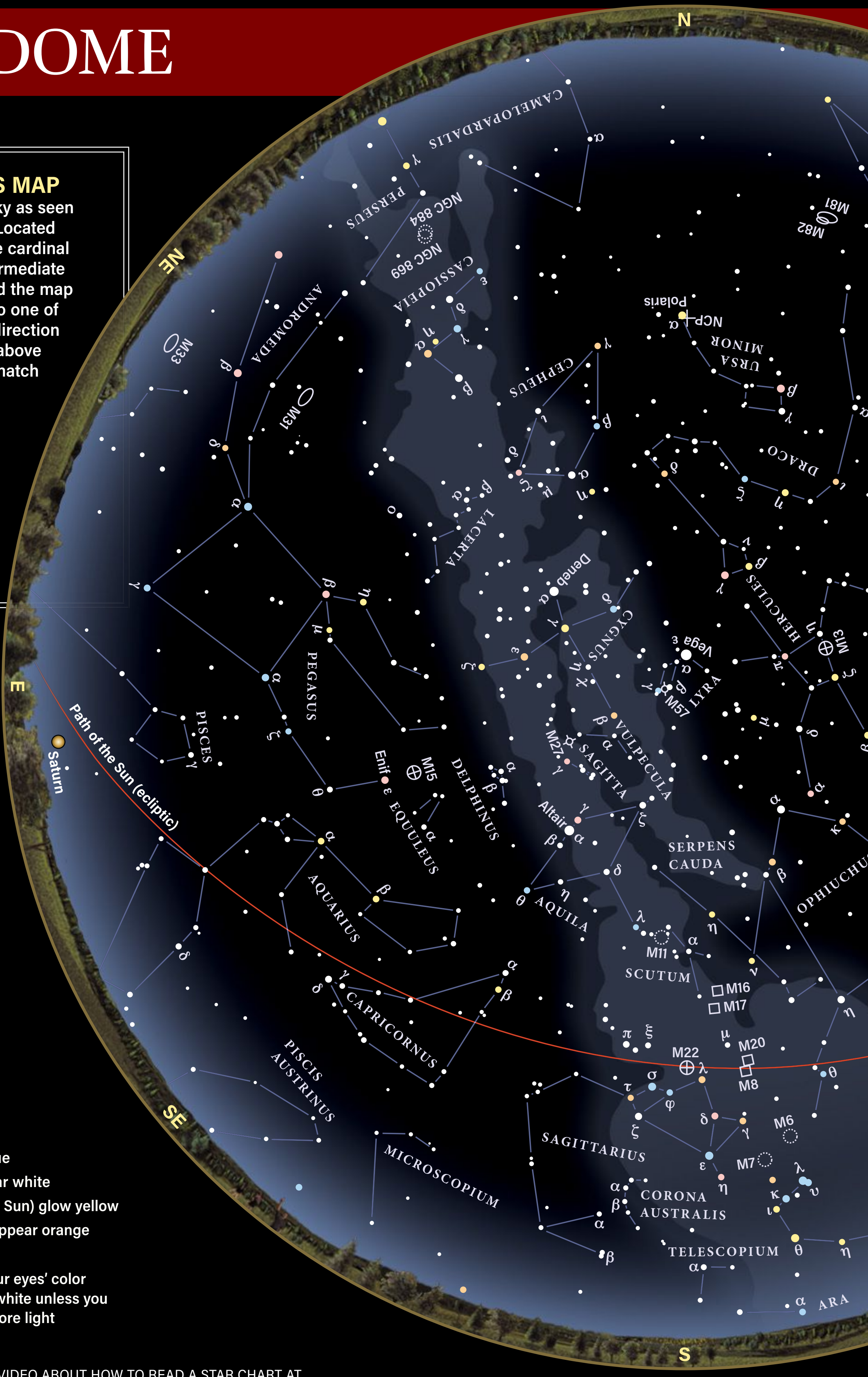
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. August 1
10 P.M. August 15
9 P.M. August 31

Planets are shown at midmonth



N
NE
E
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CAMELOPARDALIS
PERSEUS
NGC 884
NGC 869
CASSIOPEIA
ANDROMEDA
M33
M31
M81
M82
Polaris
NCP
URSA MINOR
CEPHEUS
DRACO
LACERTA
Deneb
CYGNUS
Vega
LYRA
M57
HERCULES
M13
PEGASUS
PISCES
Saturn
Path of the Sun (ecliptic)
Enif
M15
DELPHINUS
EQUULEUS
M27
SAGITTA
VULPECULA
Altair
SERPENS CAUDA
OPHIUCHU
AQUILA
AQUARIUS
M11
SCUTUM
M16
M17
CAPRICORNUS
PISCIS AUSTRINUS
M22
M20
M8
M6
M7
SAGITTARIUS
MICROSCOPIUM
CORONA AUSTRALIS
TELESCOPIUM
ARA

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- □ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

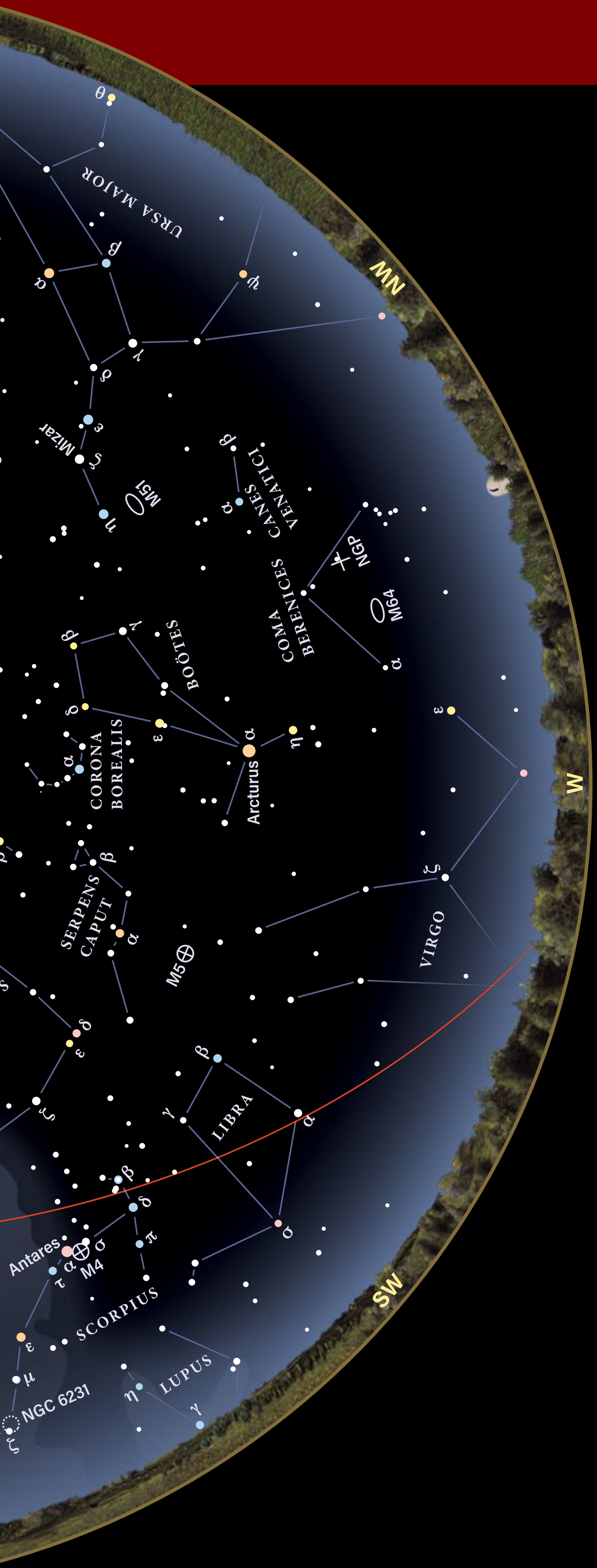
● Sirius
● 0.0 • 3.0
● 1.0 • 4.0
● 2.0 · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- ■ The hottest stars shine blue
- ■ Slightly cooler stars appear white
- ■ Intermediate stars (like the Sun) glow yellow
- ■ Lower-temperature stars appear orange
- ■ The coolest stars glow red
- ■ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



AUGUST 2025

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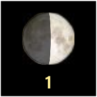
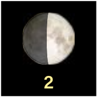
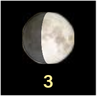
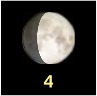
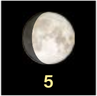
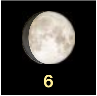
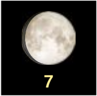
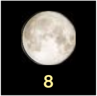
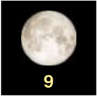
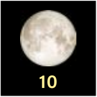
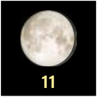
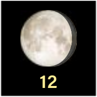
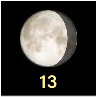
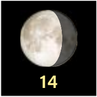
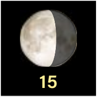
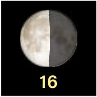
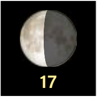
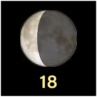
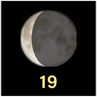
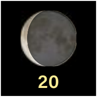
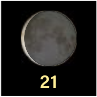
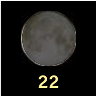
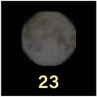
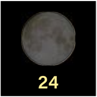
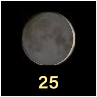
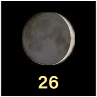
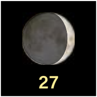
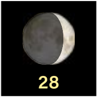
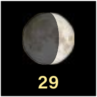
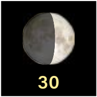
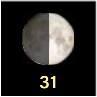
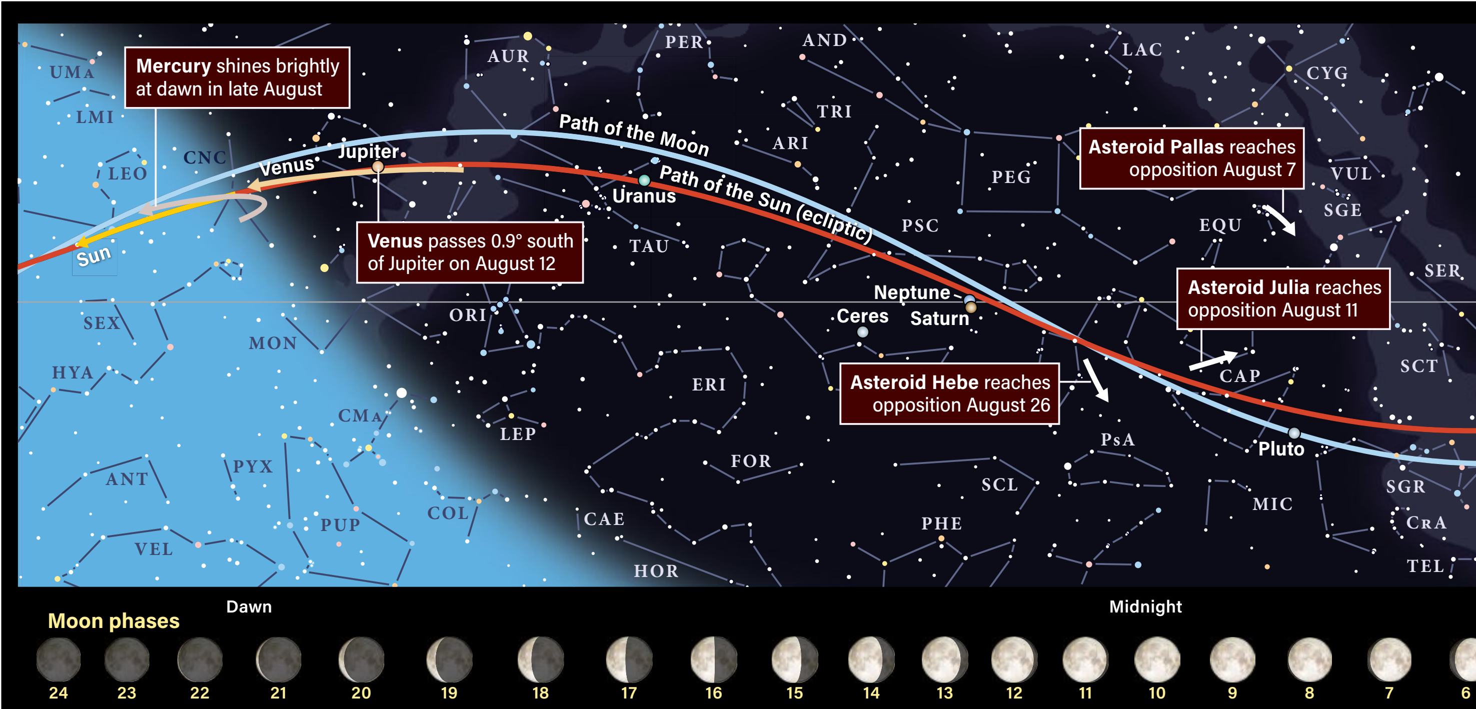
					 1	 2
 3	 4	 5	 6	 7	 8	 9
 10	 11	 12	 13	 14	 15	 16
 17	 18	 19	 20	 21	 22	 23
 24	 25	 26	 27	 28	 29	 30
 31	**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

CALENDAR OF EVENTS

1 First Quarter Moon occurs at 8:41 A.M. EDT
The Moon is at apogee (251,134 miles from Earth), 4:36 P.M. EDT
3 The Moon passes 0.6° south of Antares, 10 P.M. EDT
6 Saturn passes 1.1° south of Neptune, 6 A.M. EDT
7 Asteroid Pallas is at opposition, 5 P.M. EDT
8 The Moon passes 0.009° north of Pluto, 1 A.M. EDT
9 Full Moon occurs at 3:55 A.M. EDT
10 Mercury is stationary, 2 P.M. EDT
11 Asteroid Julia is at opposition, 5 A.M. EDT
12 Venus passes 0.9° south of Jupiter, 4 A.M. EDT
The Moon passes 4° north of Saturn, 11 A.M. EDT
The Moon passes 3° north of Neptune, noon EDT
Perseid meteor shower peaks
14 The Moon is at perigee (229,465 miles from Earth), 1:59 P.M. EDT
15 Dwarf planet Ceres is stationary, 9 P.M. EDT
16 Last Quarter Moon occurs at 1:12 A.M. EDT
The Moon passes 5° north of Uranus, 4 P.M. EDT
19 Mercury is at greatest western elongation (19°), 6 A.M. EDT
The Moon passes 5° north of Jupiter, 5 P.M. EDT
20 The Moon passes 5° north of Venus, 7 A.M. EDT
21 Venus passes 7° south of Pollux, 5 A.M. EDT
The Moon passes 4° north of Mercury, noon EDT
23 New Moon occurs at 2:07 A.M. EDT
26 Asteroid Hebe is at opposition, 10 A.M. EDT
The Moon passes 3° south of Mars, 1 P.M. EDT
27 The Moon passes 1.2° south of Spica, 11 A.M. EDT
29 The Moon is at apogee (251,374 miles from Earth), 11:34 A.M. EDT
31 First Quarter Moon occurs at 2:25 A.M. EDT
The Moon passes 0.7° south of Antares, 7 A.M. EDT

PATHS OF THE PLANETS


Mercury shines brightly at dawn in late August

Venus passes 0.9° south of Jupiter on August 12

Asteroid Pallas reaches opposition August 7

Asteroid Julia reaches opposition August 11

Asteroid Hebe reaches opposition August 26

UMA
LMI
LEO
CNC
SEX
HYA
MON
ANT
PYX
VEL
PUP
CMA
COL
LEP
ORI
AUR
PER
AND
TRI
ARI
TAU
ERI
FOR
CAE
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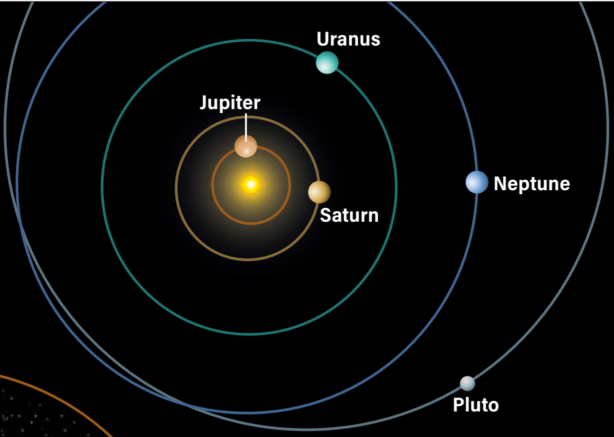
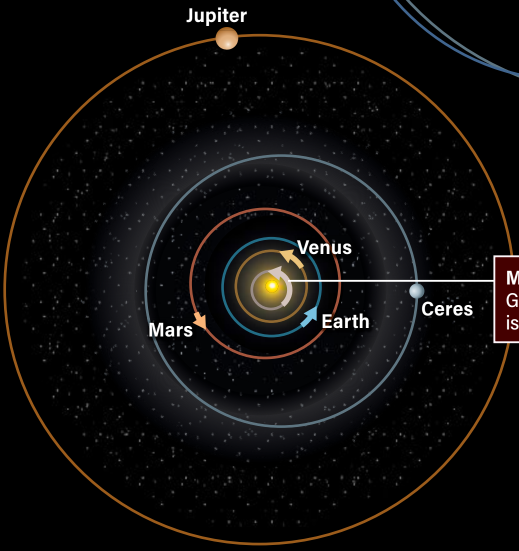
SCL
PSC
PEG
LAC
CYG
VUL
SGE
EQU
SER
SCT
CAP
PsA
MIC
SGR
CrA
TEL
Sun
Venus
Jupiter
Uranus
Path of the Moon
Path of the Sun (ecliptic)
Neptune
Ceres
Saturn
Pluto
Moon phases
Dawn
Midnight
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.

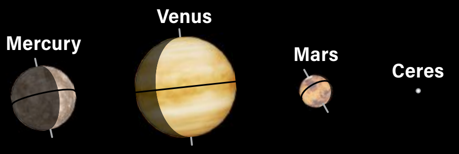

Uranus
Jupiter
Saturn
Neptune
Pluto


Jupiter
Venus
Mars
Earth
Ceres

Mercury
Greatest western elongation is August 19

THE PLANETS IN THE SKY

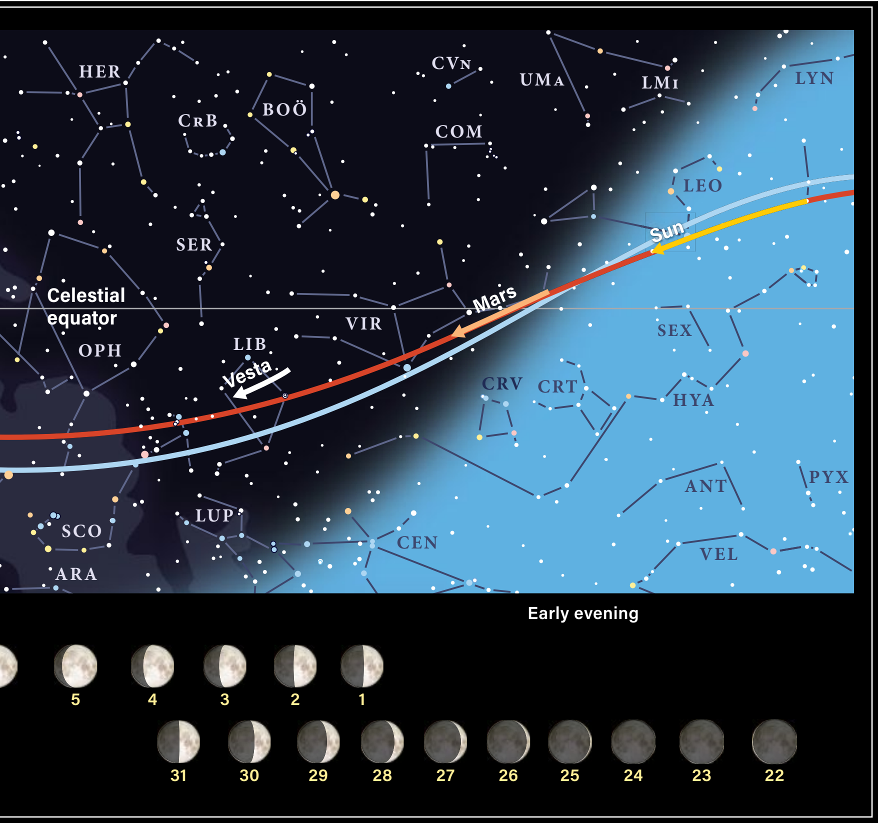
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Mercury
Venus
Mars
Ceres

PLANETS	MERCURY	VENUS
Date	Aug. 15	Aug. 15
Magnitude	0.7	–3.9
Angular size	8.5"	13.3"
Illumination	26%	80%
Distance (AU) from Earth	0.796	1.255
Distance (AU) from Sun	0.349	0.722
Right ascension (2000.0)	8h26.0m	7h13.2m
Declination (2000.0)	17°03'	21°35'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

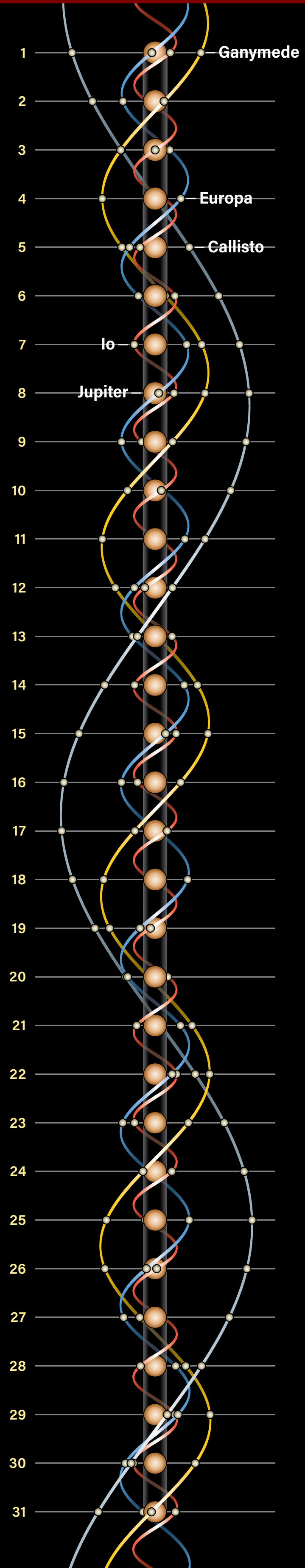
AUGUST 2025

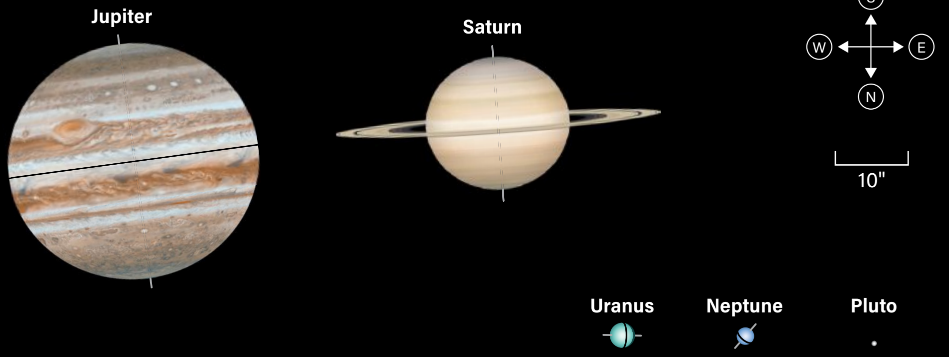

HER
CVN
UMA
LMI
LYN
CRB
BOÖ
COM
LEO
Sun
SER
Mars
Celestial equator
VIR
SEX
OPH
LIB
Vesta
CRV
CRT
HYA
PYX
ANT
SCO
LUP
CEN
VEL
ARA
Early evening
5
4
3
2
1
31
30
29
28
27
26
25
24
23
22

Callisto
Europa
Io
Ganymede

JUPITER'S MOONS

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.




Jupiter
Saturn
S
W
E
N
10"
Uranus
Neptune
Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15
1.6	8.4	–1.9	0.7	5.7	7.7	15.1
4.3"	0.6"	33.3"	19.0"	3.6"	2.3"	0.1"
95%	98%	100%	100%	100%	100%	100%
2.189	2.265	5.924	8.750	19.644	29.098	34.376
1.598	2.959	5.161	9.561	19.515	29.888	35.326
12h17.9m	1h21.5m	7h01.9m	0h06.4m	3h55.2m	0h07.2m	20h19.7m
–1°27'	–6°12'	22°37'	–1°57'	20°08'	–0°42'	–23°27'

SKY THIS MONTH

— *Continued from page 29*

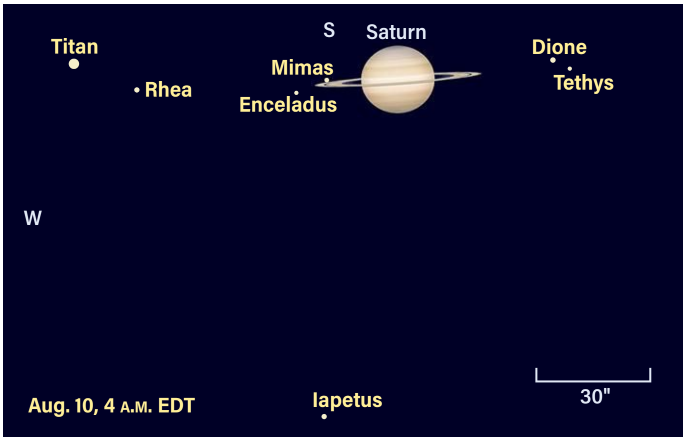
WHEN TO VIEW THE PLANETS

EVENING SKY
Mars (west)
Saturn (east)
Neptune (east)

MIDNIGHT
Saturn (east)
Uranus (east)
Neptune (east)

MORNING SKY
Mercury (east)
Venus (east)
Jupiter (east)
Saturn (southwest)
Uranus (east)
Neptune (southwest)

All together



Iapetus is visible north of Saturn overnight on Aug. 9/10 as it heads for western elongation. Saturn's other bright moons also cluster nearby; some will be easier to spot than others.

A second Titan shadow transit occurs Aug. 18/19, with ingress beginning at 1:26 A.M. EDT on the 19th in the eastern half of the U.S. (still the 18th for those in the west). Nearly two and a half hours later, the shadow is midway across the disk. The transit ends by 5:30 A.M. CDT. Observers able to see Titan pass due north of Saturn will notice the pair's separation is less than on Aug. 3. Next month, Titan begins transiting as well.

Saturn's family of moons includes Tethys, Dione, and Rhea, all orbiting interior to Titan and shining at 10th magnitude. Additionally, Iapetus stands 1.5' due north of Saturn Aug. 9/10, shining around 11th magnitude. It heads west of the planet for the rest of the month, brightening to magnitude 10.2 by the time it reaches greatest western elongation 9.5' west of Saturn on Aug. 30.

Uranus stands 4.3° south of the Pleiades (M45). The planet moves eastward, with a few similarly bright stars nearby to aid its identification with binoculars.

Uranus shines at magnitude 5.8 in early August, brightening 0.1 magnitude by midmonth. There's a pair of 6th-magnitude stars due west of the planet: 13 and 14 Tauri. On Aug. 1, Uranus is 2.4° west of 14 Tau. By Aug. 31, the gap increases to 2.9° and Uranus has slowed to almost a halt, about to turn around in a retrograde loop in the first week of September.

Another pair of stars useful to find Uranus is 37 and 39 Tau. Brighter 37 Tau is magnitude 4.4 and stands 4.5° southeast of M45. Uranus and this star form a triangle with M45, with Uranus at the lower right (southwestern) corner. Watch the slowly changing shape of this triangle through binoculars as Uranus moves. A telescope will show the 3.6"-wide, bluish-green-hued disk of the planet under steady sky conditions.

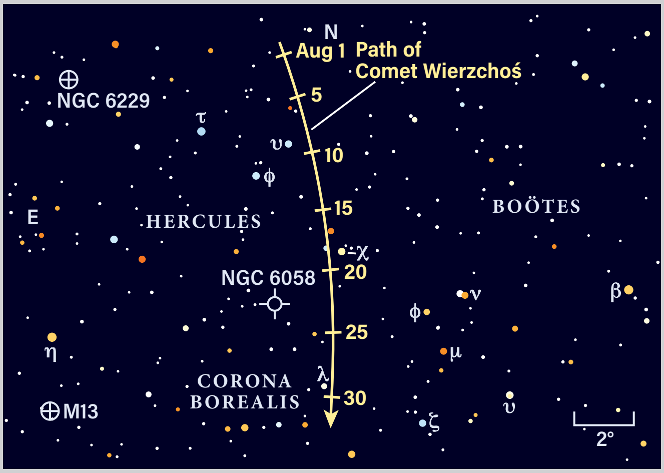
Venus rises around 3 A.M. local daylight time on Aug. 1, shining at magnitude –4. An hour before sunrise it is 20° high in the eastern sky. It maintains a similar altitude for most of the month, crossing Gemini and heading for a spectacular conjunction with Jupiter.

Through a telescope on the 1st, Venus displays a 75-percent-lit disk 14" across. By the end of August, the phase expands to 84 percent and the disk shrinks to 12", owing to the planet's increasing distance from Earth.

The gap between Venus and **Jupiter** quickly closes. By Aug. 11, they rise 1.2° (two Moon-widths) apart. The conjunction occurs the following morning, the 12th, when they appear 0.9° apart. For a few days on either side of this date,

COMET SEARCH | Rising out of the depths

Comet C/2024 E1 (Wierzchoś)



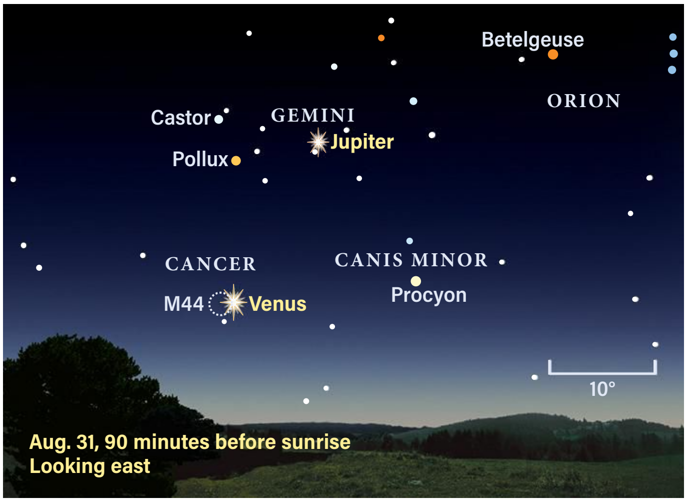
Comet Wierzchoś brightens night by night as it slowly loops inward, passing 11th magnitude in September and 9th magnitude in late October.

TIME DEALS OUT smooth averages over the centuries. But on our short human timescales, we see the random absurdity of super-faint comets for three months, followed by November's clutch of several decent telescopic ones.

Comet C/2024 E1 (Wierzchoś) may reach 4th magnitude in January as it arcs closer to the Sun than Venus. This month, however, it's a shy 12th-magnitude fuzz high in Hercules. Grab a 10-inch or bigger scope, get yourself under dark country skies, and crank up your navigation skills or turn on your go-to as Wierzchoś slides along the unremarkable boundaries of Hercules, Boötes, and Corona Borealis.

Start with a hit of Hercules' marvelous M13, then follow up with its distant sibling, globular NGC 6229 at magnitude 9.9, as a warm-up. Power past 150x to get a sense of small, faint targets. On your way to the fringe, claim the faint planetary NGC 6058 — a nebula half the apparent size of Jupiter. Compare its structure and brightness to the comet.

A dazzling pair



Aug. 31, 90 minutes before sunrise
Looking east

By Aug. 31, Venus has moved into Cancer and rises together with M44 in the morning sky. Binoculars will show the pairing best.

the two planets are a fantastic sight.

There have been 12 conjunctions between these planets in the past decade (including the triple conjunction of 2015), but some occur too close to the Sun to be observed. The next conjunction occurs in June 2026, when they will be 1.6° apart in the evening sky. Their 2027 conjunction is not observable, so the next time they appear this close is November 2028, again in the morning sky.

On the 19th, the crescent Moon joins the scene 7° above Jupiter, which is now magnitude –2. On the 20th, Venus stands 4.5° south of the Moon.

The Beehive Cluster (M44) stands 1.4° northeast of Venus Aug. 31. Venus rises more than two hours before the Sun, so the dazzling meeting of planet and cluster is plain to see. Grab binoculars for the best view.

If you're an early riser, Jupiter should definitely be on your August observation list. The gas giant rises shortly before 4 A.M. local daylight time on Aug. 1. By Aug. 31, it's up 90 minutes earlier. Located centrally in Gemini the Twins, Jupiter starts the month at magnitude –1.9. On Aug. 1, it's just over 10° from Venus.

Jupiter's low altitude means telescopic views are challenging. However, Jupiter remains visually appealing in twilight and details in its dynamic atmosphere are visible as dusky, delicate swirls. The four Galilean moons track back and forth as they orbit with periods ranging from two to 17 days. In the coming months, many transits across the face of Jupiter will be visible as the planet climbs higher in the sky.

Mercury reached inferior conjunction with the Sun July 31 and moves into the morning sky by the second week of August. On the 12th, it shines at magnitude 1.4, a challenging target.

Eagle-eyed observers might catch Mercury at magnitude 1 on the 14th, 3° high in the eastern sky an hour before sunrise. Jupiter and Venus in Gemini are a good guide for lining up the ecliptic. Draw a line through the duo toward the ground — Mercury lies near that line, close to the horizon in the brightening twilight.

Mercury reaches greatest western elongation on the 19th, standing 19° west of the Sun. It's now magnitude 0 and 5° high an hour before sunrise — much easier to see. The challenge will be to spot M44 2° due north of Mercury. The dim stars will be best seen from high elevation with a clear eastern horizon.

Look for an attractive crescent Moon nearly 5° north of Mercury on the 21st. At magnitude –0.3, Mercury is quite easy to spot.

Mercury continues to brighten but drops lower each morning. On the last morning of August, it reaches magnitude –1.2 and hangs about 19° below Venus. It's now clearly visible 45 minutes before sunrise, standing 3° above the eastern horizon.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS |

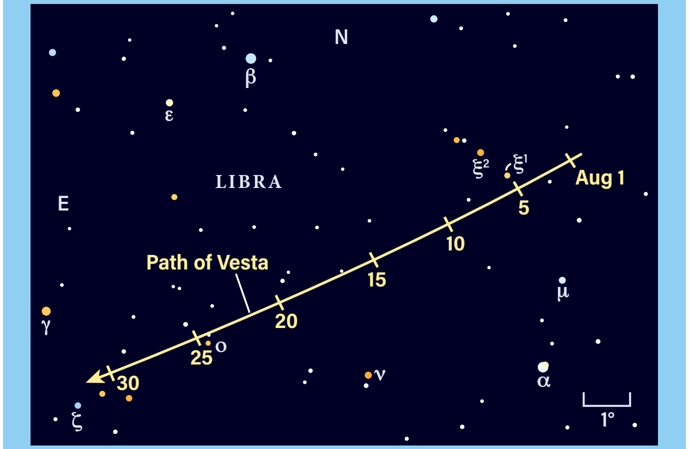
Not hanging in the balance

SPLITTING THE UPRIGHTS of the celestial Scales — unaided-eye stars Alpha (α) and Beta (β) Librae — binocular-easy asteroid 4 Vesta glides amongst standout star patterns as well as empty fields. Its gradual slump from magnitude 7.2 to 7.6 shouldn't challenge you much from the suburbs.

To track our target, sketch in a logbook the arc of five stars, starting with the lovely double star Alpha Lib (Zubenelgenubi). Every couple of nights add Vesta's dot, leaving enough space on the left to capture two weeks of movement. Repeat for the last week of August as Vesta moves from Omicron (ο) Lib toward the quad of Zetas (ζ). The best night to see displacement at medium power in a scope is on the 9th. Vesta forms the heel of a hockey stick shape that approaches a right angle over two to three hours.

Asteroids on occasion pass in front of stars in an occultation. Visit www.lunar-occultations.com/iota/iotandx.htm and explore the links under "Asteroid Occultation Information" to find events for your location. You may already have most of the gear needed to capture science-worthy measurements. If not, it's still cool to watch a star wink out for a second.

Balancing act



Vesta should be easy to track this month, sliding through central Libra.

GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

A GALAXY CLUSTER CONUNDRUM

JWST observations of the Phoenix Cluster support a theory that other clusters challenge.

BY RICHARD TALCOTT

SCIENTISTS HAVE A GOOD IDEA HOW STARS should form in the central galaxies of rich clusters. The hot gas surrounding a cluster's dominant innermost galaxy cools rapidly, sparking furious star formation. The problem: No one had found evidence for this cooling gas, and most central galaxies don't create many stars.

Astronomers suspect the solution to this so-called cooling-flow problem lies with the supermassive black hole that lurks at the heart of each central galaxy. As matter falls toward the black hole, it forms an accretion disk where temperatures soar to millions of degrees. The disks can amplify existing magnetic fields and ignite twin jets of high-speed particles that burst out perpendicular to the disk in opposite directions. The particles inject energy into the galaxy's surroundings, preventing the gas from cooling.

AN EXCEPTION IN PHOENIX

It's no wonder astronomers wanted to use the James Webb Space Telescope's (JWST) unique capabilities to explore the Phoenix Cluster. The cluster's central galaxy turns at least 500 solar masses of gas into stars each year. Few other such galaxies convert more than 10 solar masses per year. And this happens despite the galaxy having a supermassive black hole that weighs roughly 10 billion solar masses and generates strong jets.

This isn't the only reason the cluster and galaxy stand out. The Phoenix Cluster ranks among the most massive known, holding some 2 trillion solar masses. It also has the highest X-ray luminosity of any cluster. Meanwhile, its central galaxy places among the largest ever identified, with a diameter estimated at more than 500,000 light-years.

It might surprise you that astronomers didn't discover this exceptional cluster until 2010. It turned up in a radio survey made with the 10-meter South Pole Telescope in Antarctica. The cluster's shyness stems from its enormous distance of 5.8 billion light-years.

A NEON SIGN

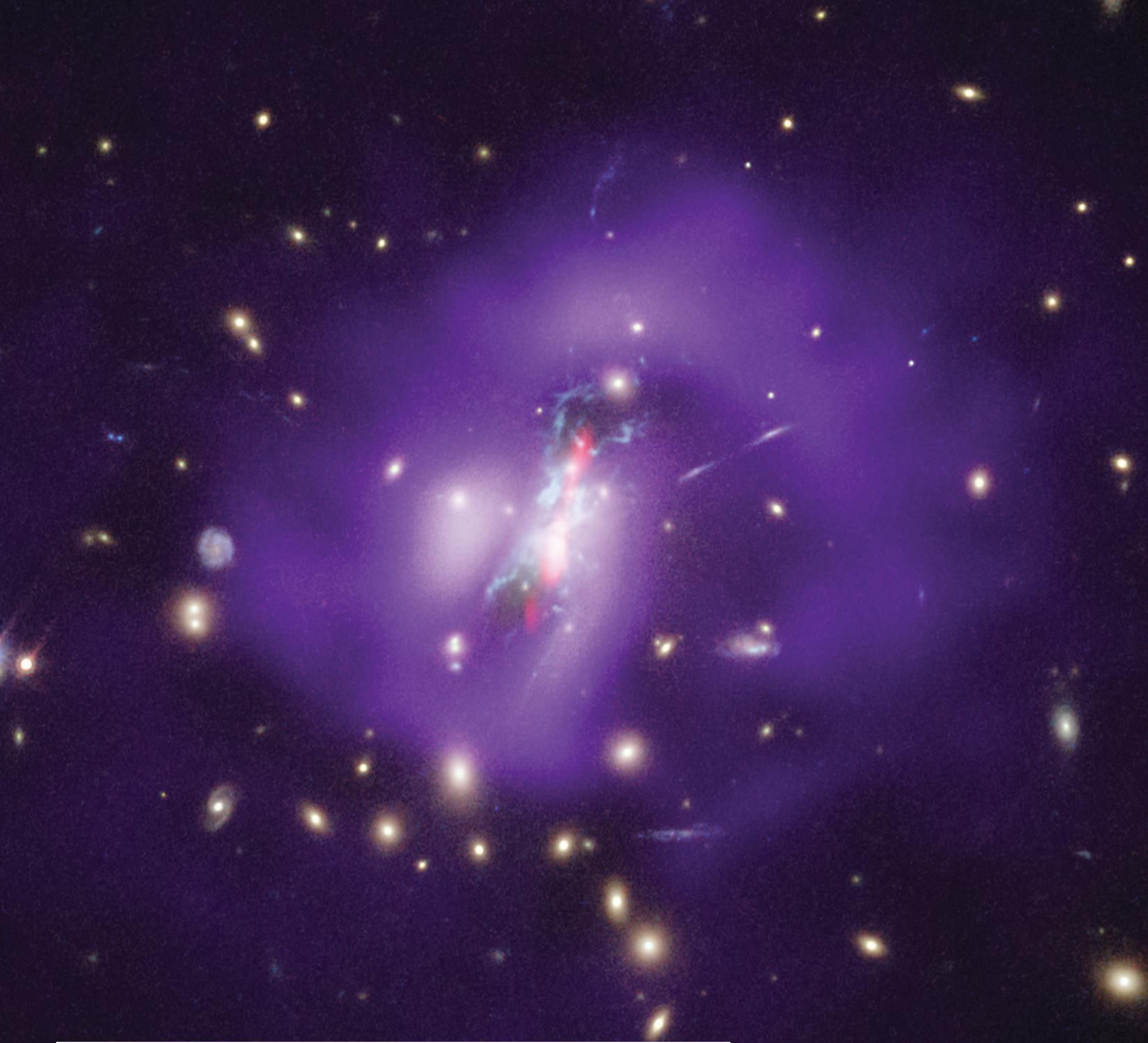
With JWST, astronomers sought a missing link in the Phoenix Cluster. Scientists earlier had observed superhot gas glowing at 18,000,000 degrees Fahrenheit (10,000,000 degrees Celsius) and much colder gas at 18,000 F (10,000 C). Any cooling flow would show up at an intermediate temperature beyond the reach of any other telescope.

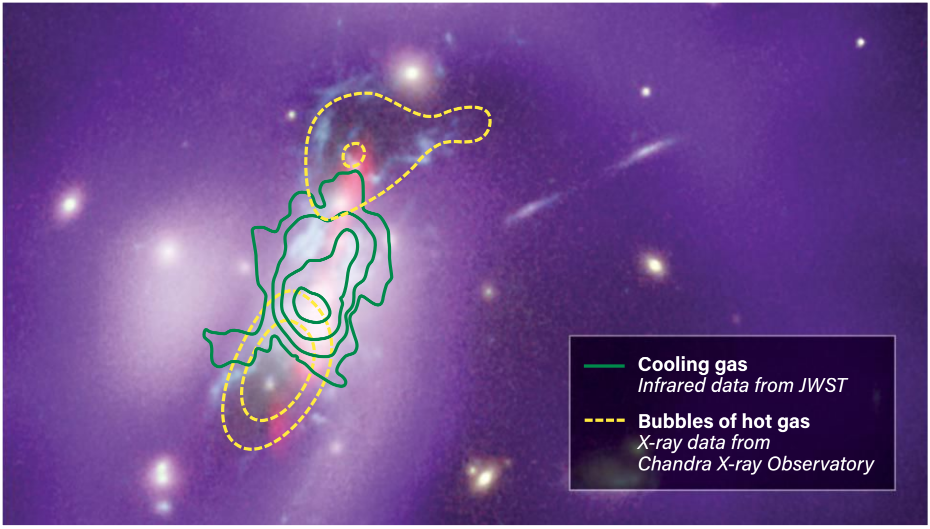
"Previous studies only measured gas at the extreme cold and hot ends of the temperature distribution throughout the center of the cluster. It was not possible to detect the warm gas that we were looking for," said MIT astronomer Michael McDonald, principal investigator of the JWST program, in a press release. "With Webb, we could do this for the first time."

The researchers used JWST's Medium-Resolution Spectrometer to map emissions from neon VI, neon atoms that have lost five electrons. It tracks the cooling gas at temperatures around 540,000 F (300,000 C). "In the mid-infrared wavelengths detected by Webb, the neon VI signature was absolutely booming," said MIT graduate student Michael Reefe, lead author on the team's paper published in the Feb. 5 issue of *Nature*. Most importantly, this warm gas lies between the cavities that trace the hot gas and the cold gas where stars are forming.

The cooling flow matches what astronomers once expected to find in clusters but had not seen before. This could mean such flows represent brief episodes, lasting only 10 million years or so, and we see the Phoenix Cluster at this special time. Even such a short lifetime wouldn't explain the lack of intense star formation in other clusters, however, raising the possibility that the one in Phoenix is unique. The scientists now plan to study more typical clusters to better understand these extreme environments.

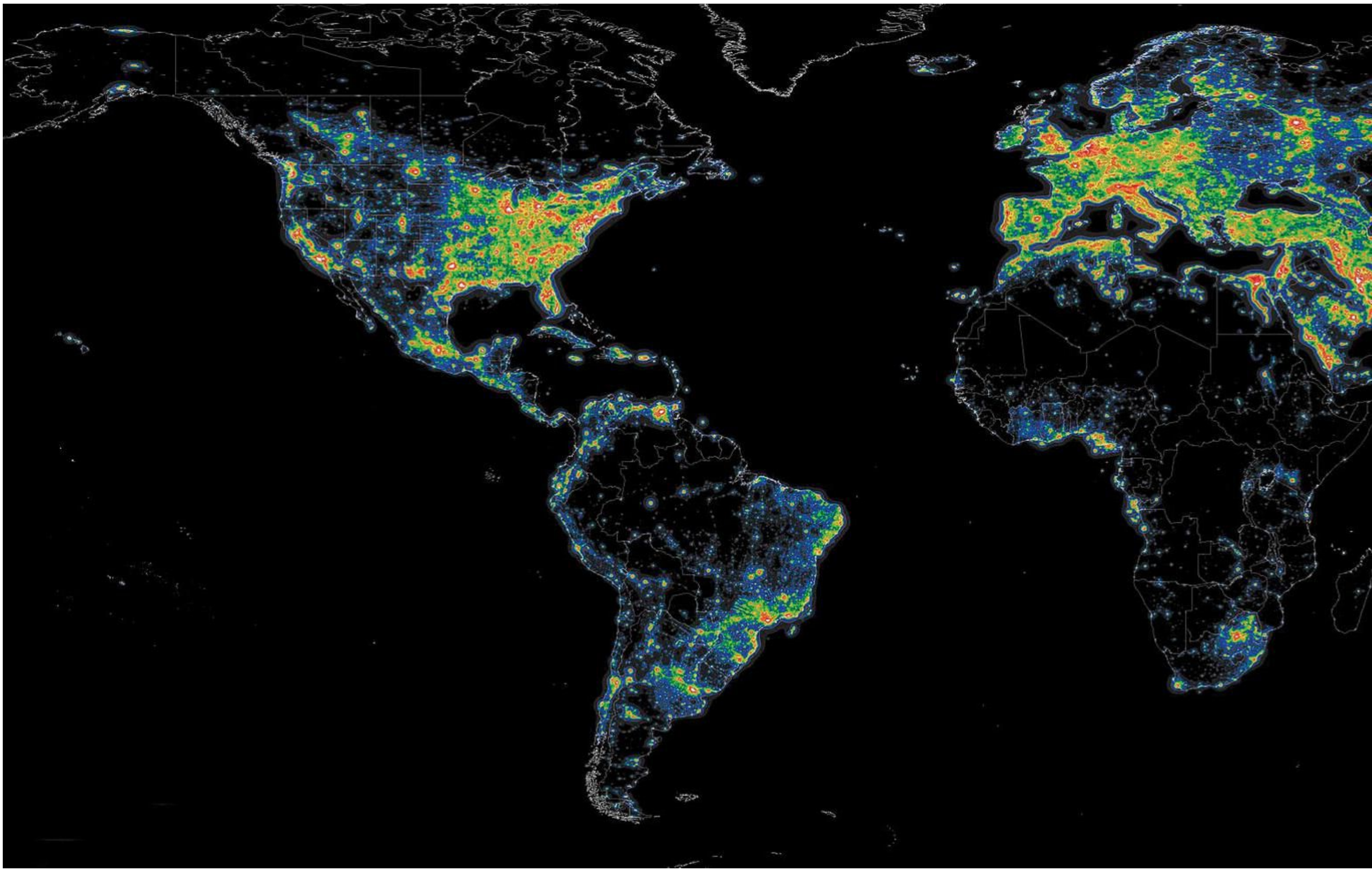
Contributing Editor ***Richard Talcott*** *wrote about JWST's observations of the interstellar medium near the Cassiopeia A supernova remnant in the July issue.*




Cooling gas
Infrared data from JWST
Bubbles of hot gas
X-ray data from Chandra X-ray Observatory

ABOVE: The Hubble Space Telescope, Chandra X-ray Observatory, and Very Large Array (VLA) radio telescope combined to create this portrait of the Phoenix Cluster. Chandra recorded hot gas (shown in purple); optical light from Hubble showed galaxies (yellow) and cold gas where stars are forming (light blue); and the VLA revealed radio jets (red) emanating from a hidden supermassive black hole. NASA, CXC, NRAO, ESA, MICHAEL MCDONALD (MIT)

LEFT: Adding spectroscopic observations from the James Webb Space Telescope (JWST) traces the cooling gas that triggers the conditions for a massive starburst in the Phoenix Cluster. This view uses the same color coding as the image above, overlaying it with JWST data showing the cooling gas and bubbles of hot gas. NASA, CXC, NRAO, ESA, MICHAEL MCDONALD (MIT), MICHAEL REEFE (MIT)



SKY GLOWS you should know

If you see an odd light in the sky, fear not — it has a scientific explanation.

BY KEN WILSON

OUR SKY IS FULL OF WONDERFUL OBJECTS. The Sun, the Moon, planets, and stars all vie for attention on the cosmic stage. Look a little closer, however, and you'll also find intriguing sky glows ranging from ghostly to glorious.

I usually give them a passing glance while observing or imaging. But some of them deserve more than just a quick look, so I created this list of the most common glows to know.

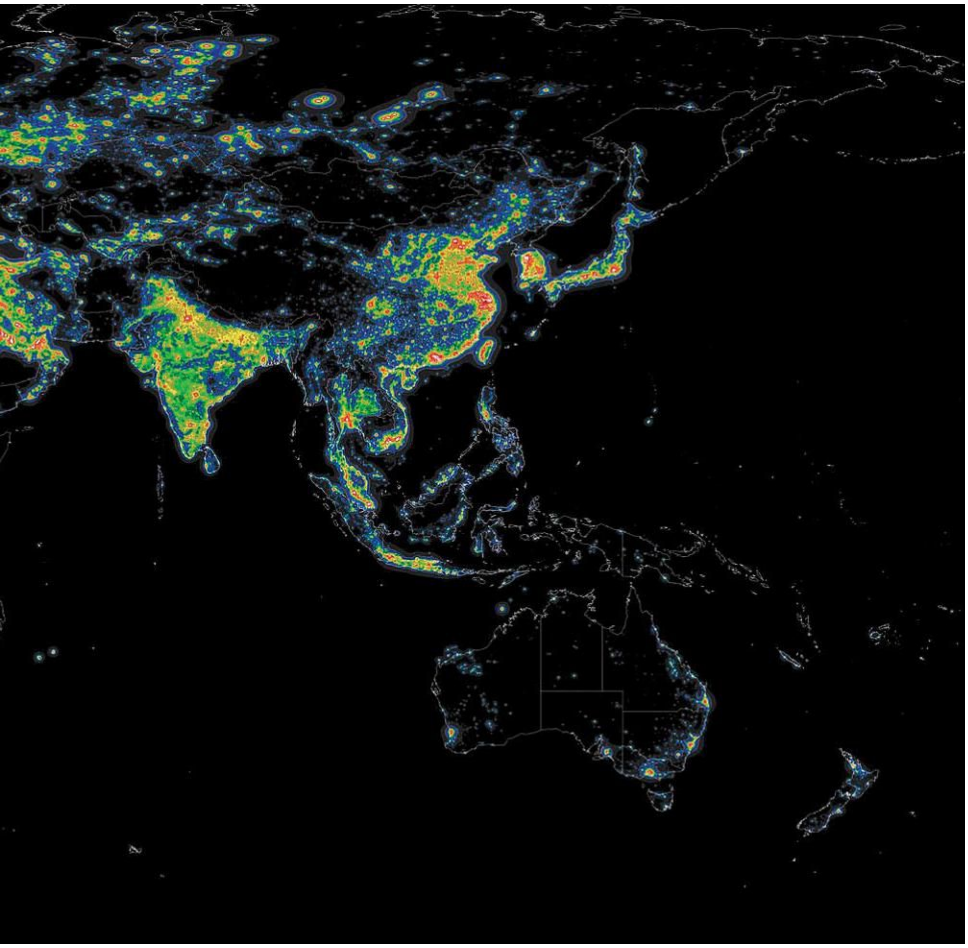
Light pollution

Let's start with the bad one: light pollution. At its worst, it can wipe out views of all other sky glows.

Often appearing as a diffuse dome of light, it's usually found along the horizon in the direction of cities. The bigger or closer the city, the bigger the light pollution dome. And unlike most natural sky glows, these don't move as Earth turns, although they may dim late at night when some businesses turn off exterior lighting.

Aurorae

Another large glow is seen along the northern horizon (southern horizon if you live south of the equator): the aurora borealis



CLOCKWISE FROM ABOVE:
This world map of light pollution shows the state of that sky glow as of Sept. 29, 2021. DAVID LORENZ/WIKIMEDIA COMMONS

This unusually brilliant aurora was photographed in 2004, two solar cycles ago. ROBERT B. SLOBINS

From a dark location in the Northern Hemisphere, the Milky Way stretches from horizon to horizon in the winter and summer. CHRIS COOK

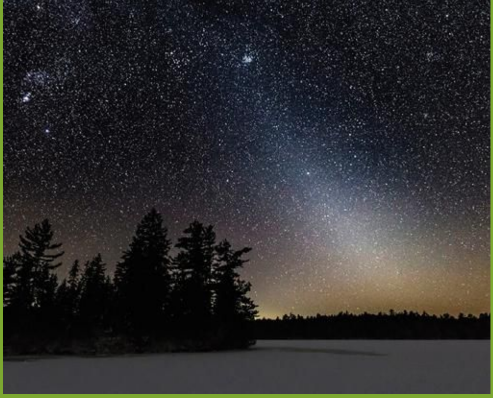
The Large Magellanic Cloud is a famous sky glow that can be easily seen from the Southern Hemisphere. MARCO LORENZI

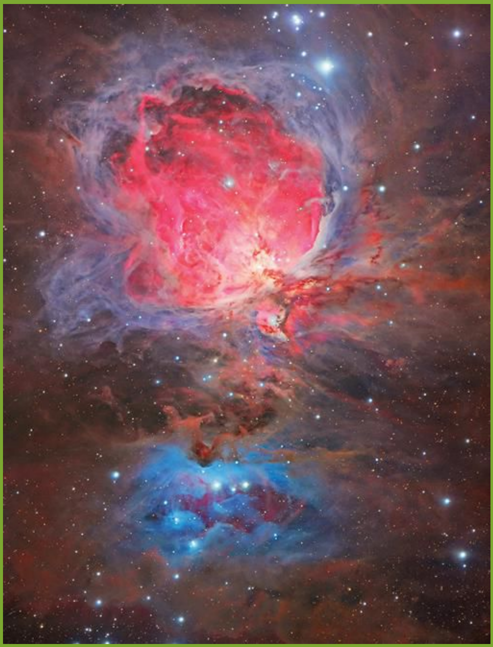
(or aurora australis). The closer to the North or South Pole you live, the higher in the sky they appear. These spectacular displays of light happen when charged atomic particles from solar eruptions get caught in Earth's magnetic field and funnel down into the upper atmosphere. There, they ionize oxygen and nitrogen atoms 50 to 100 miles (80 to 160 kilometers) above us.

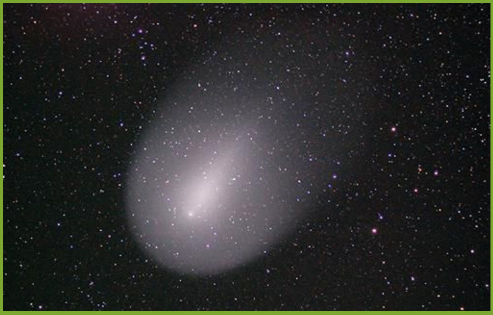
The ionized gases glow green (most common), red, pink, blue, or violet. A weak aurora may look like a small, distant cloud. Strong aurorae can fill the sky and take different forms, including rays, rayed arcs, coronas, and curtains. When a powerful solar storm buffets Earth's magnetic field, an aurora can change in a matter of seconds by undulating both horizontally and vertically. We see auroras more often near the peak of the 11-year sunspot cycle, which is happening now.

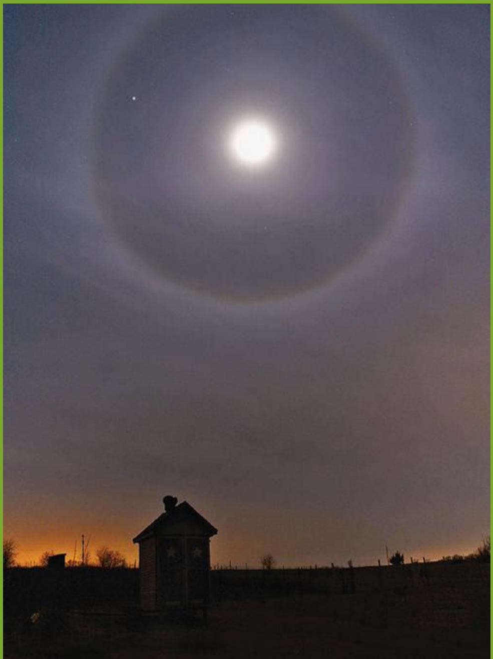
Milky Way & Magellanic clouds

All stars visible to the naked eye are part of our Milky Way Galaxy, a vast spiral of several hundred billion stars mixed with lots of gas and dust. On any clear dark night, especially summer and winter evenings, we see the combined glow of these stars as an arc stretching from horizon to horizon. But the Milky Way is easily hidden by light pollution or even by a bright Moon. But from a dark site, it will appear as a pale, ragged band of gray light stretching through many constellations, including Cygnus, Orion, and Sagittarius. From non-light-polluted









locations, you'll see dark patches and lanes in it caused by opaque interstellar dust that threads through our galaxy. Unlike terrestrial clouds, the Milky Way remains anchored to the stars and constellations, slowly crawling with them across the sky throughout the night.

Our Milky Way Galaxy has several satellite galaxies. Two of them are easy to see from a dark sky — if you look from the Southern Hemisphere. The Large Magellanic Cloud looks like a fuzzy, round chunk, about the size of your fist held at arm's length, broken off the Milky Way. The Small Magellanic Cloud is a smaller, similar glow about eight Full Moons in diameter.

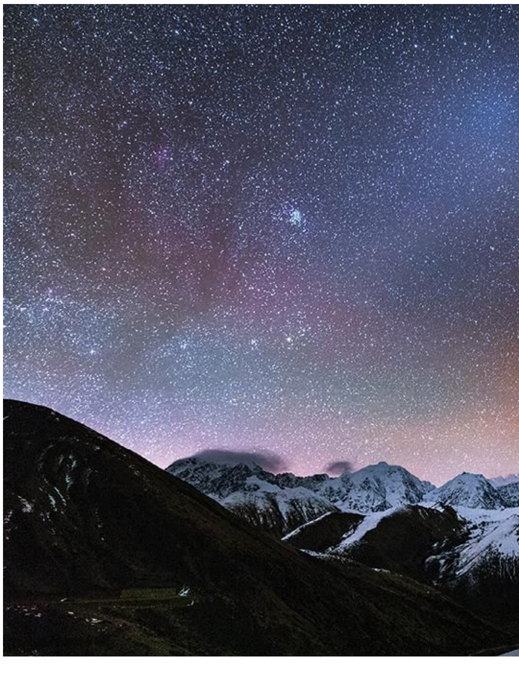
Zodiacal light & gegenschein

The solar system is a messy place. In addition to the big objects, there's a lot of dust floating around out there, mostly in the plane of the ecliptic (which is aligned with the zodiacal constellations). While that dust is usually unseen, under the right conditions, sunlight can scatter off it, making it visible to our earthly eyes. Most often you'll see it as a colorless, faint, cone-shaped patch along the eastern or western horizon. In the Northern Hemisphere, zodiacal light is best seen in the east just before dawn from September through November and in the west right after dusk from late January through early April.

The dust that causes zodiacal light also shows up as a fainter spot ever-so-slightly brighter than the background sky, called the gegenschein (or counterglow). Look for it along the ecliptic at the point opposite the Sun from us. It's best seen around midnight when it's highest in the sky and in front of constellations with a lot of faint stars, like Virgo and Pisces.

Deep-sky objects

Novice skywatchers are often surprised to learn that they can see galaxies, star clusters, and nebulae without a telescope. A prime autumn example is the Andromeda Galaxy (M31), a fuzzy



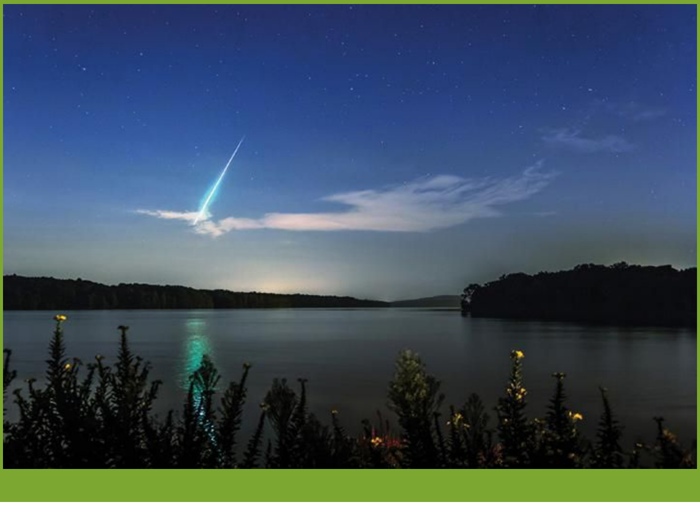
LEFT, TOP TO BOTTOM:
The zodiacal light shines brightly in the western sky from Indian Fields in Nova Scotia. The photographer used a 14mm lens and took a 20-second exposure. BARRY BURGESS

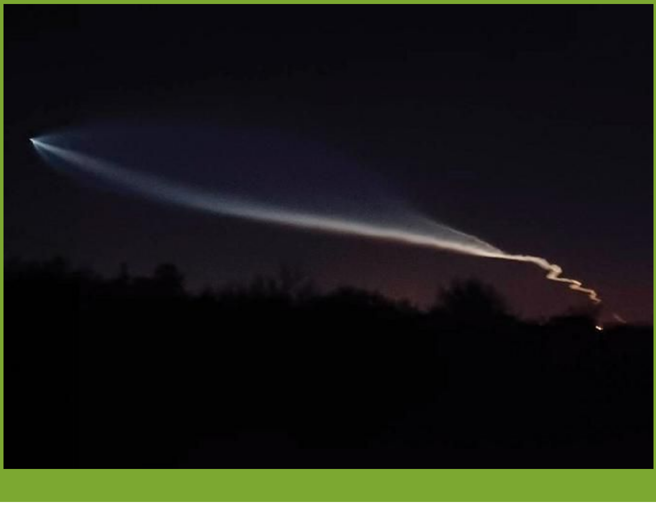
Although the Orion Nebula (M42) doesn't appear this spectacular to the naked eye, it is a deep-sky object that you can see, albeit as a tiny glowing patch in Orion's sword. TONY HALLAS

Comet 17P/Holmes was a wonderful naked-eye sky glow for several months around the time this image was taken in December 2007. DAMIAN PEACH

The photographer captured this 44°-wide lunar halo on New Year's Eve 2014 above his backyard observatory in Missouri. JARED BOWENS

RIGHT: This photographer captured the gegenschein, or counterglow, from Yaha Pass in Sichuan Province, China. The image also contains yellow and green airglow. JEFF DAI





ABOVE, LEFT TO RIGHT:
These glowing noctilucent clouds were photographed above the Arctic on June 29, 2021. EXSOMNIS/WIKIMEDIA COMMONS

This Perseid meteor created a brilliant sky glow for a few seconds Aug. 13, 2016, above Lake Nockamixon in Quakertown, Pennsylvania. LARRY KUHN

A rocket carrying Starlink satellites was launched from Vandenberg Space Force Base on June 18, 2024. It created quite the glow in the western sky of Tucson, Arizona. MICHAEL E. BAKICH

oval six times as big as the Full Moon. In winter, check out the Orion Nebula (M42), a hazy "star" in the middle of Orion's sword. Even the Hercules Cluster (M13) can be spotted on any clear, dark summer night. All these faint fuzzies will move only as fast as the fixed stars, unlike comets or meteors.

Comets

Made of dust and ice, comets are small members of the solar system that only show themselves when they approach close enough to the Sun that the ices start to sublimate. Released gas and dust balloon out into huge clouds and, for some, tails visible from Earth. At first a comet will show up as a faint starlike patch that may look like a deep-sky object. Unlike deep-sky objects, however, comets slowly change their positions against the background of stars over hours and days.

Beware of false comets. Sometimes, right after sunset or before sunrise, you'll see contrails of jets glowing from sunlight coming from below the horizon. They look like little golden comets. Unlike true comets, jets will move noticeably in just a few minutes and their tails usually won't point away from the Sun.

Lunar glows

Occasionally a large, pale ring of light will be seen encircling the Moon. These circles, which have a radius of 22°, are caused by moonlight refracted through ice crystals high above us, mainly in cirrus clouds. Other cloud formations can cause a much smaller glow, called a lunar corona, immediately surrounding the Moon's disk. It's blue close to the Moon and reddish at its edge.

Noctilucent clouds

Wispy, thin clouds of tiny ice crystals sometimes form about 50 miles (80 km) high in the atmosphere. During astronomical twilight, sunlight coming from below the horizon lights them up. They're most often seen during the summer at latitudes between 50° and 70° north or south.

Meteor trails

Also known as shooting stars or falling stars, meteors can be seen almost any clear night, suddenly streaking across the sky. These solid bits of solar system rock and metal fall to Earth all the time, glowing brightly as they heat to incandescence by compressing air molecules along their paths. The glow of a meteor is unmistakable. Sometimes you may miss the meteor but see a glowing train it leaves behind lasting from a few seconds to a few minutes.

Rocket launches

If you live downrange from any of the major rocket launch sites like Kennedy Space Center, Vandenberg Space Force Base, or Wallops Island, you might see artificial sky glows produced by night launches. Often mistaken for meteors or comets, they are best way to distinguished by the duration of their glows.

Meteors zip through the sky in a split second. Comets linger in the sky for many minutes up to several hours if the sky is clear. A rocket launch is visible for a few minutes at best. Some launches release clouds of glowing gas in order to study the atmosphere. Also, the trails left by these events often form undulating shapes because of upper-level winds.

As you can see, there are many things that set the night sky aglow. To see them, just keep your eyes on the sky. Good luck!

Ken Wilson *is a retired planetarium director who has been carefully watching the skies since 1968.*

FULL MOON: TAFFPIXTURE/ADOBE STOCK

The Full Moon typically ruins deep-sky imaging, but it's amazing what the right processing can bring out.

TEXT AND IMAGES BY
CHRIS SCHUR

Who's afraid of the Big Bad Moon?

In the late 20th century, when we still captured celestial images on film, the few days around New Moon were the only times we could image deep-sky objects. The grainy, low-sensitivity films we used back then demanded the darkest skies possible for quality portraits. When First Quarter arrived, it was time to say goodbye to astrophotography for a few weeks.

Today, with digital imaging technology, we can continue to shoot right through a Full Moon by using a few simple image-processing techniques and following half a dozen basic rules.

Don't worry, though — you can see your friends and family on cloudy days!

The sky during Full Moon

We all know the sky gets much brighter around Full Moon, comparable to the washed-out skies we see from the center of a large city. But there is another factor at work. The sky also gets much bluer due to atmospheric Rayleigh scattering, the process that scatters sunlight to make the sky blue during the daytime.

As a result, images taken at this time not only have a bright background, but are tinted various shades of blue depending on their angular distance from the Moon. Any process to mitigate these effects must include removing the blue sky background, subtracting out the luminance bias, and increasing the signal-to-noise ratio in our finished images.

Types of targets available

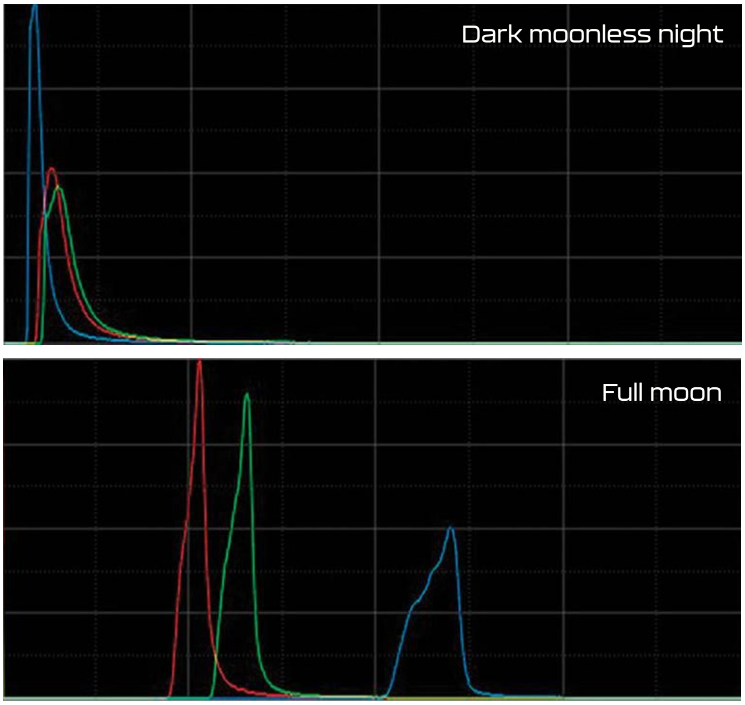
The blue color of the moonlit sky does constrain the types of objects we can successfully record. Anything with a blue tint will be greatly diminished; however, that still leaves tens of thousands of objects as targets. These include open and globular clusters, galaxies, star clouds, comet dust tails, and — with the addition of a narrowband Hydrogen-alpha (Hα) filter — emission nebulae.

As for objects you can't shoot, avoid blue reflection and planetary nebulae, comet gas tails, dark nebulae (or those with a low surface brightness), and targets with predominantly Oxygen-III (OIII) or Hydrogen-beta (Hβ) emission.

Examining the histograms

We can start offsetting the effects of a Full Moon in an astroimage by comparing a histogram of the target under dark-sky conditions to one taken during Full Moon. A histogram displays graphically the range (from black to white) of pixel values on the horizontal x-axis, and a count of the number of pixels of a given brightness along the vertical y-axis. A dark-sky

The North America and Pelican nebulae in Cygnus are popular targets. The author took this image (and all others in this story) using a 10-inch f/2.8 Newtonian reflector, a Nexus coma corrector, and an Atik 16200 CCD camera. This image combines one hour of Hα and 30 minutes of RGB exposures.



Compare these histograms for the same target on a dark moonless night (top) and during the Full Moon (bottom). Notice that during the Full Moon, the peaks are far more separated and shifted to the right from the background sky glow. Our goal in processing will be to match the two histograms.

Installing a black light-shield extension on your telescope will reduce internal reflections from the Full Moon. Here, the author is adding a 20-inch (51 cm) extension to the front of his 10-inch reflector.

THE SIX RULES OF FULL MOON IMAGING

Before we shoot during Full Moon, we need to observe a few basic rules to increase the likelihood of obtaining the best possible images.

RULE #1: Extend your telescope tube with a tube of some dark, rigid material twice the diameter of the telescope tube. For example, if your telescope is 6 inches (15.24 centimeters) in diameter, extend the front by 12 inches (30.5 cm). This glare shield will prevent moonlight from shining into the tube and creating unfixable gradients.

RULE #2: Take normal flats and darks to minimize vignetting, which would complicate gradient removal.

RULE #3: Select a target no closer to the Moon than 45°. This avoids the brightest part of the sky with the strongest color and gradients.

RULE #4: Shoot in the early evening to keep the Moon low in the east.

RULE #5: Increase your exposures by about four times to increase the signal-to-noise ratio. For most images, if you expose during a Full Moon for an hour (which is pretty standard these days), you will get close to the equivalent of a 15-minute shot from a dark site. This is plenty to record details in deep-sky objects. The idea here is to limit the subexposures to keep the sky in each subframe from clipping the white end of the histogram.

RULE #6: Select targets that don't fill more than 50 percent of the field of view. This will allow more sky to work with when removing the strong gradients we'll be encountering.

histogram from a site with no light pollution will have the red, green, and blue humps closely spaced, with the green and red a bit higher due to the colors of natural airglow. Also, the black gap before the data begin will be short, with only a small luminosity component to the sky.

A histogram of the same type of target in a Full Moon sky shows that the three colors are much farther apart, with the blue and green much brighter than the red. The blue histogram is also wider due to the contribution of the blue sky background. All three colors are much farther to the right, indicating a large luminance component to the sky. Finally, the overall noise level is higher during Full Moon.

Our goal is to correct (or at least compensate) for all these factors and make the histograms during Full Moon look just like they were shot at a dark-sky site. From there, we can use processing procedures for shots taken under dark skies.

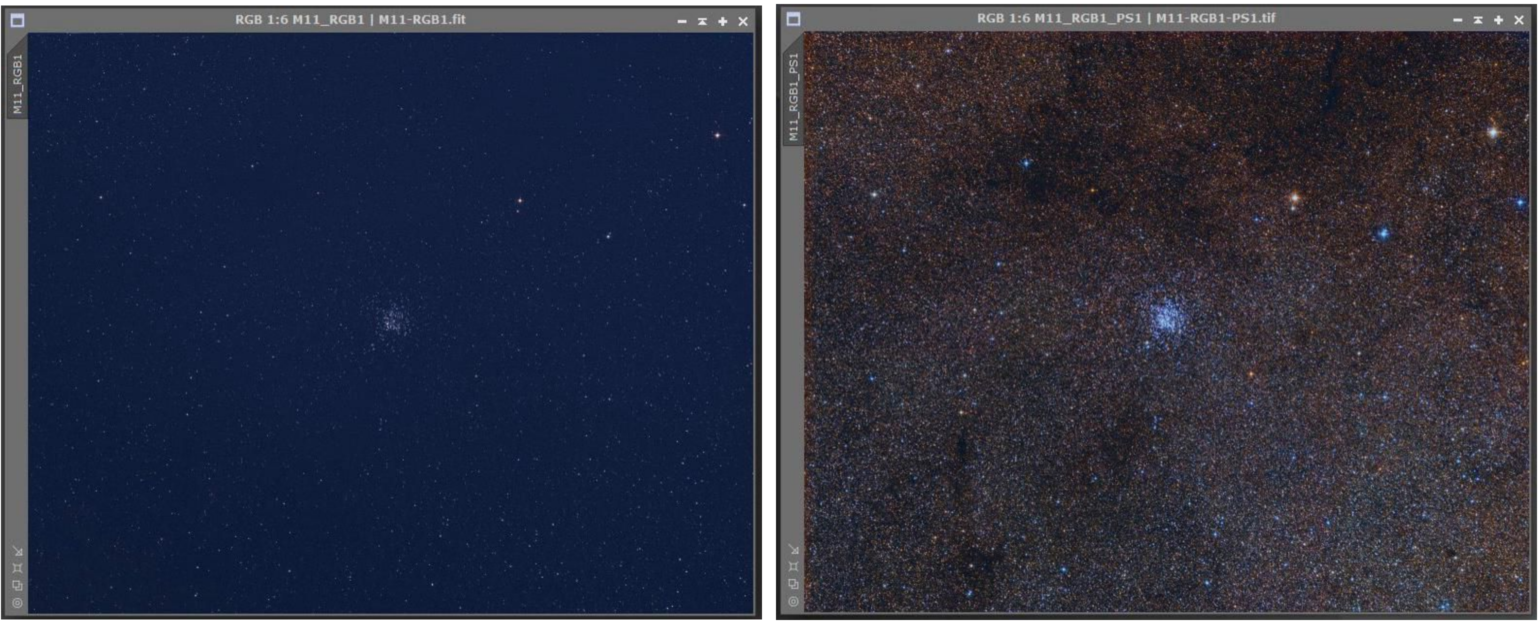
Image processing concepts

With raw images in hand, we now can process them so the effects of the Full Moon are — for the most part — mitigated. Removing the effects of moonlight is a simple two-step process that can be done with nearly any image-processing software.

Start by removing the excess blue and green for a neutral color balance. Next, subtract the bright luminance from the sky background. After these two steps, we can process our images in the same fashion as our dark-sky images.

Using Adobe Photoshop

After calibration of darks, flats, and bias frames, stack as you would for any raw image. Save the combined raw image as a 16-bit TIFF, and open it in Photoshop. Start by removing the blue cast. Common sense would suggest that to do this, we simply have to subtract it or tweak the color balance


RGB 1:6 M11_RGB1 | M11-RGB1.fit
M11_RGB1
RGB 1:6 M11_RGB1_PS1 | M11-RGB1-PS1.tif
M11_RGB1_PS1

The RAW image of open cluster M11 on the left bears little resemblance to what it looks like after processing. Here, the effects of the Full Moon have been mitigated. Note the beautiful star colors and the dark nebula in the background.

sliders to remove the blue. Not so! This always results in a strongly yellow subject and stars, even when the sky background is set for a neutral gray. This is because the blue histogram not only contains the blue sky, but also the target data.

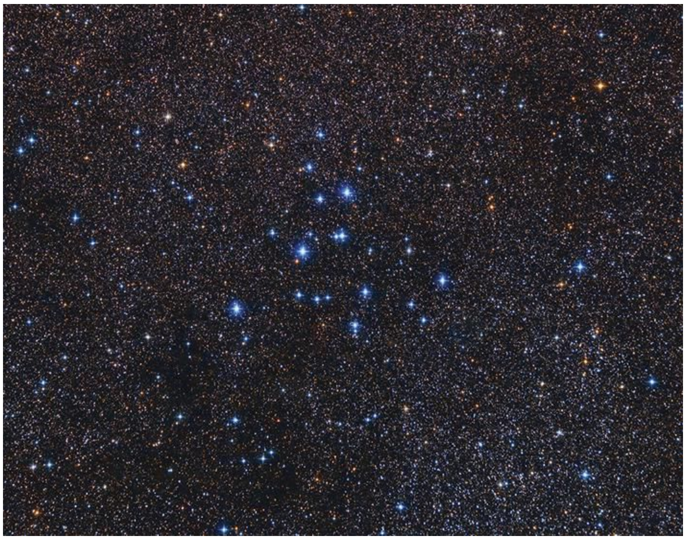
But no worries, there's a simple way to get the blue out and retain the subject's color balance. We do this by aligning the tops of the peaks of all three color channels. Because the red is usually the lowest value, adjust the blue and green sliders on the Levels palette to bring them down to match the red channel. Don't worry about the different widths, just align the peaks. Hit OK, and you're almost done.

With the blue color neutralized, we next remove the strong luminance bias. Open the Levels palette again, set all three colors in the RGB mode, and move the left slider up until the background is a dark neutral gray. Try not to make it jet black — a value around 25 is best — or you'll hide the faint details.

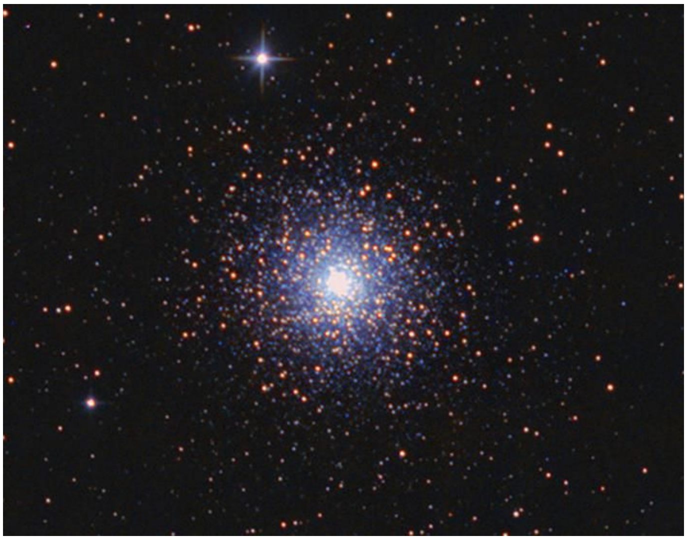
You're done with removing the Moon's bright glow. Now you can do your standard nonlinear curves, color and saturation adjustments, and sharpening to finish the job.

Using PixInsight

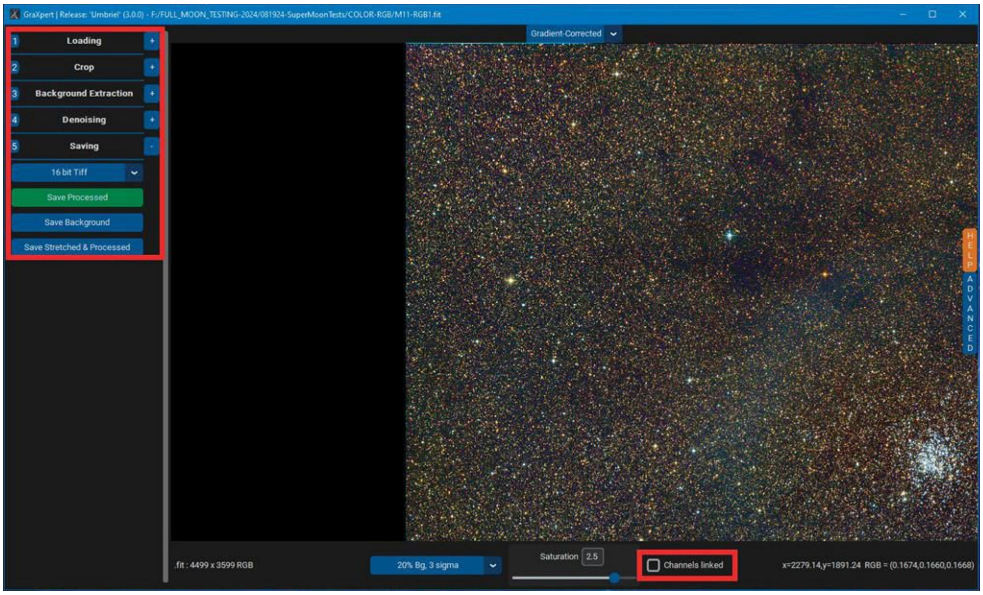
It's actually easier to use PixInsight to do these tasks than it is to use Photoshop because we can apply a linked screen stretch to the image



It's hard to believe that this one-hour image of M39 in Cygnus was taken during Full Moon. The beautiful blue supergiants seem to float in front of a rich Milky Way backdrop.



The author imaged globular cluster M15 in Pegasus during the Full Moon on Nov. 15, 2024. Note the gold and blue supergiants in this rendition. Recording this range of color in globular clusters is a true test of excellent color balance.


GraXpert | Release: 'Umbriel' (3.0.0) - F:/FULL_MOON_TESTING-2024/081924-SuperMoonTests/COLOR-RGB/M11-RGB1.fit
1 Loading +
2 Crop +
3 Background Extraction +
4 Denoising +
5 Saving -
Save Processed
Save Background
Save Stretched & Processed
Gradient-Corrected
HELP
ADVANCED

16 bit Tiff

20% Bg, 3 sigma

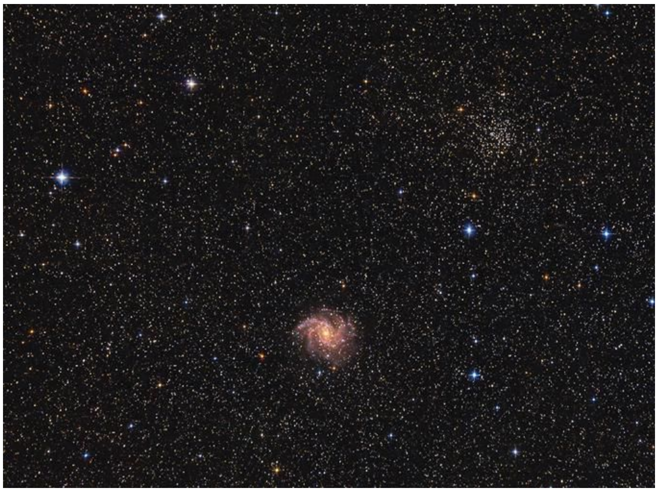
Saturation 2.5

☐ Channels linked

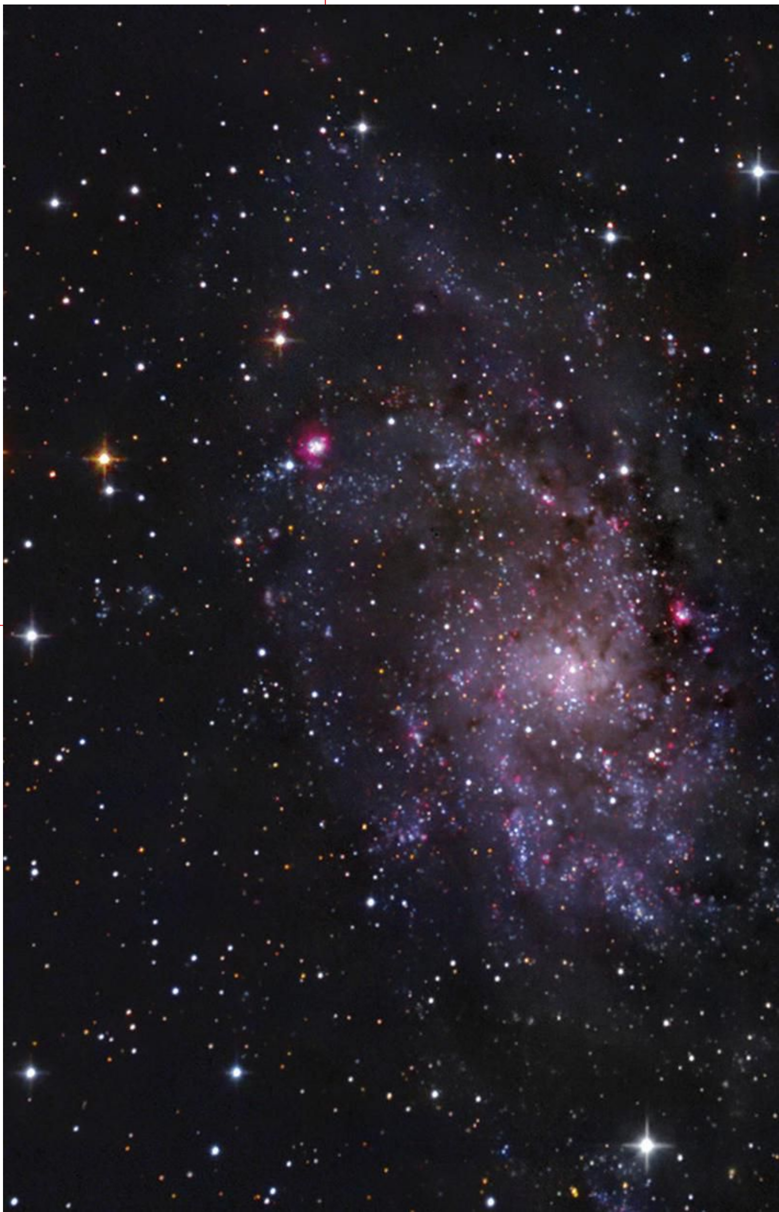
.fit : 4499 x 3599 RGB

x=2279.14,y=1891.24 RGB = (0.1674,0.1660,0.1668)

This screenshot shows the Graxpert interface with key tabs highlighted in red. After loading the raw image, you can crop off any black borders that appear after stacking, flatten the background with Background Extraction, use Denoising to clean the background, and save the image. Make sure the "Channels linked" checkbox is not checked for proper alignment of the peaks.



The author captured two hours of exposure during a Full Moon to create this image of the Fireworks Galaxy (NGC 6946) and open cluster NGC 6939 in Cygnus. It shows that his technique can record colorful stars and a dark background.



before changing the individual histogram peaks. This makes the color balance in the raw image clearer.

The technique is the same as above: Open the histogram palette and line up the R, G, and B peaks. Then, in a similar fashion to the process in Photoshop, move the left slider to remove the luminance bias to a value of 0.1 or so. Follow with standard processing techniques to complete the image.

Using Graxpert

What if I told you there was an even better way to process images using an incredibly powerful freeware program that not only automatically lines up the histogram peaks, but removes all the gradients and has an AI denoise function to clean up those lower signal-to-noise images to perfection? On top of all that, this application also allows various stretch levels on your image and creates a perfect dark neutral gray background.

Well, it exists: Graxpert can be downloaded from https://graxpert.com. Download the standalone version 3 and you'll get the latest AI files and application. Graxpert will open any FITS or TIFF files and display them as a full-screen image, making it easy to spot fine details in your images. This will be important when we use the program for denoising later.

After opening your raw

stacked image in Graxpert, make sure you unselect the "Channels linked" checkbox at the bottom. This will make Graxpert align the three color peaks in your image. Also, crop out the black border so as not to confuse the AI flattening algorithm later. Start with the background extraction and removal tab; for most images, the AI flattening works great. Sometimes complex nebulosity will produce dark areas in the image or remove dim nebulosity. I then choose the manual RBI method and put little sample boxes in my image in the places where the sky background appears. This works really well and your images will no longer have a Moon-induced gradient.

The Pinwheel Galaxy (M33) in Triangulum shows lots of detail in this one-hour exposure taken during a Full Moon. The spiral structure is clear, stars are resolved in the arms, and red HII regions stand out.

The next tab is Denoising, and I just leave it at the AI position. The program may ask you if it's OK to download the latest AI. Say yes. Version 10 and later work fantastically. The slider can be set from halfway to full strength. Start with the 50-percent level and see how it looks. This denoise application is one of the most powerful available. It does take time to do its job, but you will not be disappointed with how it cleans up your images.

Finally, when saving images select the "No Stretch" option at the bottom if you want to do your own nonlinear stretch later, or one of the other choices if the stretch it suggests looks good. A level of 15 percent is usually optimal. In the Save tab, you have several options. I usually choose "Save Processed" for an image on which I will do the nonlinear stretch later. If you like the suggested stretch, you can save it as "Save Stretched and Processed."

More processing

As with any raw image that has been calibrated, gradient corrected, and denoised, you can finish the processing in your favorite program. Just remember that Graxpert by default saves images as 32-bit TIFF files, and you may want to change this to 16-bit.

Using your favorite software, start with a nonlinear stretch using the Histogram palette and move the middle slider to the left as desired. Reset the black level after each adjustment with the left slider. When the image looks right, do final color and saturation adjustments like you would for any dark-sky image. Finally, you can crop the image, rotate for a standard north-up orientation, set final background brightness, and resize for your intended use.

The author stands in front of one of his imaging setups at his Arizona home.

Narrowband imaging

Most city-dwellers have discovered that you can record some remarkable images from the bright city skies using various narrowband filters. This is generally true for moonlit skies, with one exception. While Hα and Sulfur-II filters are at the red end of the spectrum and are less affected by the blue moonlit sky, the OIII filter with its bluish-green color does not fare so well.

In fact, shooting either OIII or Hβ narrowband images is usually a losing battle. Even with incredibly long exposures, they don't reveal much except sky fog. So go ahead and shoot Hα in the moonlight, but save the blue end of the spectrum for that next moonless night.

Combining RGB data that has had moonlight mitigated with Hα images is straightforward. I usually layer the Hα data over the RGB data in Photoshop, then colorize the Hα data with a shade of red or pink. This is easily done with the Hue/Saturation palette and selecting "Colorize."

Then select the appropriate shade of red to tint the grayscale Hα image. Set Combine to "Lighten" in the Layers palette, and you can set the brightness, contrast, and transparency to the most suitable mix. This retains all the beautiful RGB star colors and any blue nebulosity, while bringing in the narrowband data to create the enhancement you find most pleasing.

Conclusion

So who's afraid of that Big Bad Moon? You shouldn't be anymore. Although you must follow some rules with a slightly limited selection of deep-sky targets, you can now take on projects you might not normally attempt. Many new targets will now be within your grasp. You have no excuse for wasting another clear night — no matter the phase of the Moon!

Chris Schur *collects photons above Happy Jack, Arizona, and is one the world's top astroimagers.*

The DWARF 3 scope is a GIANT in its field

DwarfLab's updated smart scope has a larger lens, an equatorial option, and an enhanced sensor.

BY PHIL HARRINGTON

Telephoto
Wide-Angle
DWARF LAB

Astronomy is one of the fastest changing sciences, and the equipment we use to explore and record the universe is advancing just as quickly.

Smart telescopes epitomize the evolving equipment scene, combining a telescope, digital camera, and automated tracking in one sleek package. They allow novice astrophotographers to capture stunning deep-sky images on their first clear night without the steep learning curve that was standard just a few years ago.

That trend is perfectly illustrated by the DWARF 3 smart telescope from DwarfLab. Not long after I reviewed their DWARF II model in *Astronomy*'s August 2024 issue, the company announced its next generation. So, to put the DWARF through its paces, I arranged to receive a unit for review from the company.

The familial resemblance between the DWARF II and DWARF 3 is unmistakable, but the DWARF 3 takes the best of the DWARF II and pushes the boundaries of what a tiny telescope can do.

Great optics in a small package

At the heart of the DWARF 3 is a 35mm f/4.3 apochromatic objective composed of multiple extra-low dispersion (ED) lens elements. The telescope's optical design uses advanced coatings to enhance light transmission and reduce chromatic aberration, delivering crisp and vibrant images.

The DWARF 3 uses Sony's highly sensitive IMX678 CMOS sensor, known for its exceptional low-light performance. With a high dynamic range and low noise levels, this sensor captures even faint objects with surprisingly short exposures. Its resolution supports high-quality images and video, making it versatile for various astrophotographic needs.

The objective's 150mm focal length pairs well with the IMX678 sensor in terms of image scale. The small sensor significantly crops the field of view, resulting in an effective focal length of 737mm. The cropping removes any edge distortion while also making the DWARF 3 great for capturing larger deep-sky objects, as well as the Sun and the Moon. The focal length, however, falls short for capturing detailed planetary images.

The DWARF 3 has a second lens for wide-field imaging — a welcome addition. The previous DWARF version also had a second lens, but it was not designed for astrophotography. The DWARF 3's second lens is just 3.4mm in diameter with a true focal length of 6.7mm. It has an effective focal length of 45mm thanks to sensor cropping. It can be used in all imaging modes, including time-lapse video for creating stunning starscapes.

The DWARF 3 also includes an innovative filtering mechanism with three built-in filters; the filter can be selected before starting an image. The "Astro" filter is best for star clusters and galaxies, enhancing the details while doing night photography. The "Dual-Band" filter is perfect for improving contrast of narrowband targets like emission and planetary nebulae. Finally, the "VIS" filter is designed for daytime terrestrial photography, such as landscapes and wildlife.

PRODUCT INFORMATION

DWARF 3 Smart Telescope
Aperture: 1.4 inches (tele); 0.13 inch (wide)
Focal length: 150mm (tele); 6.7mm (wide)
Storage: 128 GB
Lenses: Telephoto and wide-angle
Dimensions: 8.7 by 5.6 by 2.6 inches
Weight: 2.9 pounds (1.3 kg)
Price: $599.00
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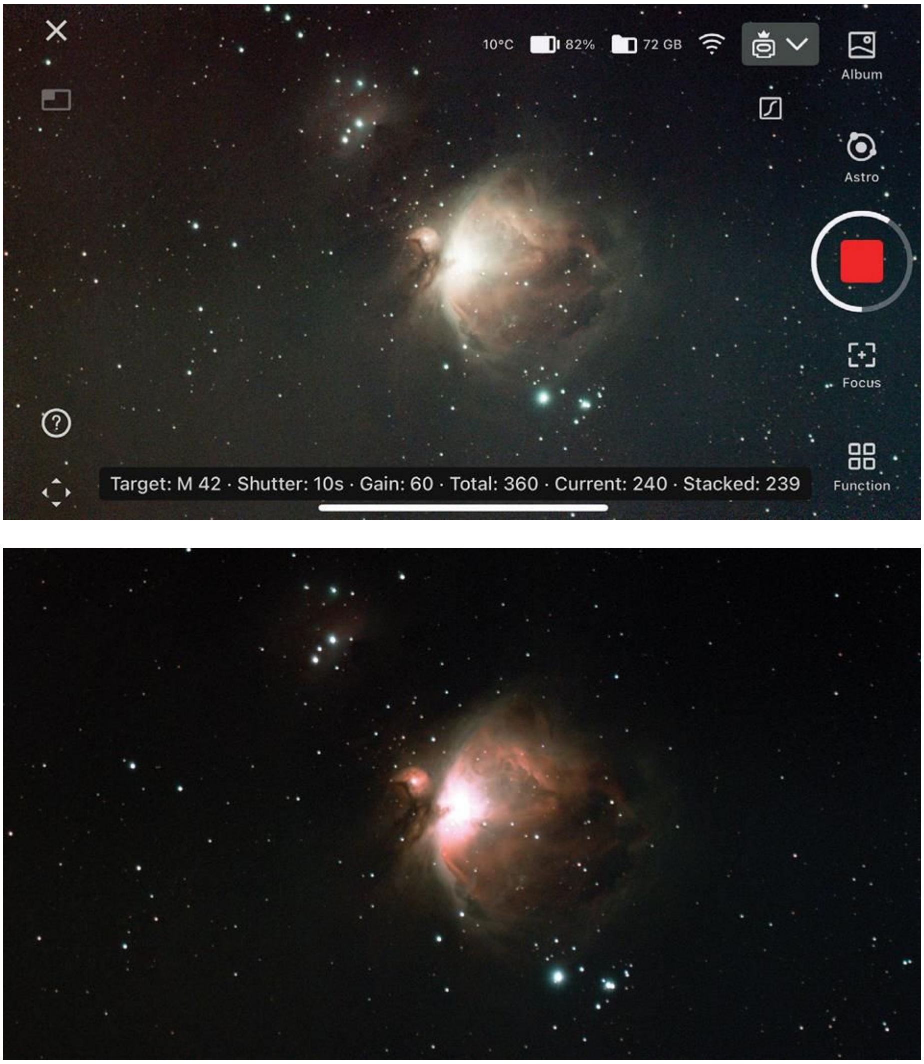


Target: M 42 · Shutter: 10s · Gain: 60 · Total: 360 · Current: 240 · Stacked: 239

The Orion Nebula (M42) comes to life on your screen with the DWARF 3's new optical design and sensor (top), especially after some post-processing with open-source programs like GIMP (bottom). PHIL HARRINGTON

Ready for action

The DWARF 3 arrived safely double-boxed inside its carrying case. The case also holds the magnetic solar filters (for both lenses), a filter pouch, a USB-C cable, and a lens-cleaning cloth. The complete package weighs just over 4 pounds (1.8 kilograms) and measures only 9½ by 6½ by 5¼ inches (24.1 by 16.5 by 13.3 centimeters).

Setting up the DWARF 3 was straightforward. After charging the internal battery, I attached the telescope to my own tripod, swung the dual lenses up so they were aimed toward clear sky, and pressed the side-mounted power button.

When I first used the DWARF 3, I opened the company's app, called DWARFLAB (compatible with both Android and iOS devices), and noticed it has undergone significant updates. It's now more intuitive, with a streamlined design that makes navigating the app a breeze. To get the show on the road, I went to Settings, and selected Connection Settings. Once there, I enabled STA Mode, which allows the smartscope to connect to your home's Wi-Fi network. The DWARF 3 can then be accessed inside and outside as long as your mobile device is also connected to your home Wi-Fi. If there isn't a local network available, the DWARF 3 can be operated directly by connecting your mobile device to the scope's internal Wi-Fi, although its range is limited.

Next, I chose the type of image to take. The options include Astro, Time Lapse, Video, Pano, and Burst. After picking Astro mode, I focused the optics by selecting "autofocus" or "∞" (infinity). I found the latter was quicker and usually quite accurate. Calibrating the telescope to the current sky allows the scope to automatically adjust its orientation for precise tracking and object location.

Objects can be chosen directly from the app's extensive database of stars, planets, galaxies, and much more. The updated app includes real-time sky conditions, providing users with comprehensive data to enhance experience. Alternatively, coordinates can be entered manually for unlisted targets, such as new comets. Once in view, the scope smoothly tracked the target as it moved across the sky, proving flawless every time.

Before capturing an image, I adjusted various settings, such as exposure time and gain (analogous to ISO), directly within the app. Other settings include subframe count, live stacking, binning, and AI enhancement. The latter does not add synthetic data, but rather enhances image quality by reducing noise, sharpening details, and improving contrast.

DWARF II vs. DWARF 3

The DWARF 3 introduces several notable upgrades over the DWARF II.

To me, the biggest is the optional equatorial mode. In its normal altitude-azimuth mode, the DWARF 3 tracks the sky in an up/down and left/right motion, while the stars appear to move in curved arcs. Although polar aligning via the app requires practice, equatorial mode enables precise single-axis tracking, eliminating the up/down, left/right motion, thus improving image quality.

Another significant improvement is the larger, apochromatic objective lens. While I praised the DWARF II in my review, the DWARF 3 takes image quality to new heights with its larger aperture and superior sensor.

I was especially happy to see that the app added multiframe stacking and a scheduling feature. The latter allows users to automate imaging by setting start times, durations, and targets.

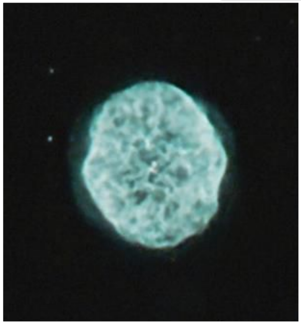
The DWARF 3 smart telescope is a testament to how far compact astroimaging technology has come. Its advanced optics, enhanced sensor, and user-friendly design appeal to beginners and experts alike.

In a world of large telescopes, the DWARF 3 stands tall.

Phil Harrington *received the Walter Scott Houston Award at Stellafane 2018 for his lifelong contributions to amateur astronomy.*

Cataloging the heavens

Lists upon lists.



ABOVE: Catalog number 1501 in the NGC is the Oyster Nebula. The author combined nine hours of exposure taken during November 2023.

RIGHT: Number 82 in Charles Messier's catalog is the Cigar Galaxy. The author captured 18.5 hours of exposure from November 2022 to March 2023 to create this image.

MOLLY WAKELING (2)

BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.

Humanity is obsessed with astronomical record keeping. The Babylonians compiled their first listing of the stars in the 12th century B.C.E. Around 1000 B.C.E., they followed it with an expanded catalog that includes familiar constellations and star clusters, as well as motions of the Sun, the Moon, and the planets. The Mayans inscribed into stone and painted onto cloth calendars and almanacs, tracking planets, eclipses, and possibly even the precession of the equinoxes.

Today, telescopes and clocks have allowed for precise records of object locations. Our most prolific surveyor of the cosmos, the European Space Agency's Gaia satellite, has measured the positions of approximately 1 billion stars and objects. A beginning astronomer can be confused by the plethora of catalogs we use to identify the deep-sky objects we seek in our telescopes, especially when many are listed in multiple catalogs. Let's explore the more common ones.

The first catalog beginning astronomers are likely to encounter is the Messier catalog.

The first catalog that beginning astronomers are likely to encounter is the Messier catalog. Named for 18th-century French astronomer Charles Messier, the register contains 109 bright objects (103 original, plus six later additions) that could be mistaken for comets by the unsuspecting observer. Because he was observing from France with a 4-inch refractor, all Messier objects are visible in the Northern Hemisphere, with the southernmost at about –35° declination. Objects range from star clusters and galaxies to nebulae and supernova remnants. Entries are numbered with the prefix M. For instance, the elegant Whirlpool Galaxy in Canes Venatici is M51.

Another common catalog is the *New General Catalogue*, or NGC. Compiled by Danish astronomer John Louis Emil Dreyer in 1888, it contains 7,840 objects, ordered by right ascension. Many of the objects are galaxies, but it also includes nebulae and star clusters. Dreyer later created two supplements, the *Index Catalogues* (IC), which list another 5,386 objects. The NGC is descended from William and Caroline Herschel's catalog first published in 1786.

For nebula lovers, the Sharpless catalog is a close friend. American astronomer Stewart Sharpless published his first catalog in 1953 with 142 objects, then added more in 1959 for a total of 312. This list is almost exclusively HII regions (emission nebulae rich in hydrogen), with a few planetary nebulae and supernova remnants in the mix, surveyed from photographic plates from the Palomar Observatory Sky Survey. Sharpless objects carry the abbreviated label Sh 2, indicating they come from his second catalog. For example, the Lagoon Nebula, also known as M8, is Sh 2–25.

Confusingly, there are two Abell catalogs — one for rich galaxy clusters, and one for planetary nebulae. They were both compiled by the same American astronomer, George O. Abell. The galactic catalog contains a total of 4,073 dense groupings of galaxies (2,712 northern and 1,361 southern), with a minimum of 50 galaxies required to qualify. This is a challenging catalog to explore, requiring large telescopes and dark skies.

The planetary nebulae catalog, published in 1966, has 86 objects. Four were later determined not to be planetary nebulae, but rather other kinds of nebulae, a ring galaxy, and an imaging artifact. Both catalogs use the identifier Abell, encompassing objects such as Abell 21 (the Medusa Nebula) and Abell 1656 (the Coma Galaxy Cluster).

These are a sampling of the catalogs that amateur astronomers most commonly encounter, but advanced astrophotographers tracking down infrequently observed objects may stumble across many more. Let these catalogs be a guide on your astronomical adventures. Happy hunting!

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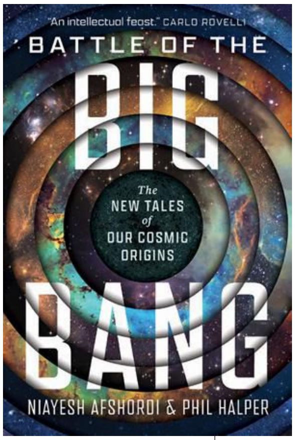
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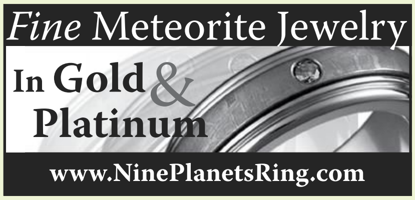
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Star varieties

Q | WHAT ARE THE FACTORS THAT RESULT IN SO MANY DIFFERENT SIZES AND CLASSES OF STARS?

Kenton Bowers
Pahrump, Nevada

A | To understand how we classify and differentiate the stars we see in the sky, we first need to understand how they are born and change throughout their lives.

Star formation begins with a massive cloud of cold gas and dust. The gas and dust then begin to clump together, and as a single clump grows in size, its gravity gets stronger. It then keeps accumulating the material around it until its gravity becomes so strong that it collapses in on itself, like a sandcastle built so tall that it can't support its own weight. As that collapse happens, the inside of the now very large clump begins to heat up because of all the pressure from the tons and tons of material on top of it.

How and when this collapse starts depends on the overall mass of the gas and dust cloud and what types of elements are inside it. Compared to a smaller cloud, a more massive cloud can produce stars that are more massive — and make a larger number of them. A cloud with a lot of metals (defined by astronomers as elements heavier than helium) can make massive stars with high concentrations of those elements and make them quickly, while clouds with more hydrogen and helium tend to make smaller stars more slowly.

The baby star that is born from one of these clouds has a very specific size, mass, temperature, and elemental makeup based on the collapse. Once this star's core gets hot enough to start fusing hydrogen into helium, we define it as a main sequence star, which includes those like our Sun. As the star gets older and evolves, its mass and elemental composition still play a big role. Bigger stars fuse elements in their cores much faster than smaller ones, causing them to run out of fuel sooner and therefore die earlier. They are astronomy's version of "live fast, die young." Stars with lots of heavy elements also tend to evolve more quickly than stars with fewer heavy elements, and can lose a lot of their mass throughout their lives. This combination of processes makes every star a little different (size, temperature, brightness, etc.), which leads to our classification of stars.

So, long story short, the two primary factors that result in so many different types of stars and dictate how we classify them are the size of the molecular clouds the stars are born from and what kinds of elements are inside of them.

Jessica Ranshaw
Astronomy Graduate Student,
Indiana University Bloomington, Indiana

BIG STARS ARE ASTRONOMY'S VERSION OF "LIVE FAST, DIE YOUNG."

Q WHAT IS THE CIRCLE THAT EARTH'S AXIS TRACES OUT IN ITS 26,000-YEAR PRECESSION CYCLE? WHAT BRIGHT STARS ARE CLOSE TO IT?

Tim Boyle
Nishinomiya, Japan

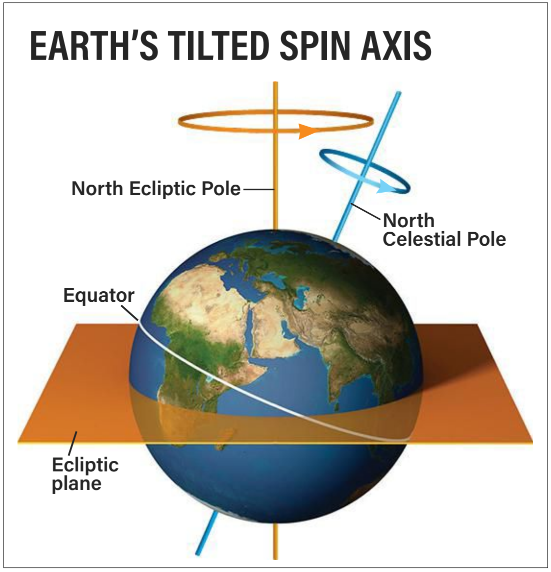
A As Earth orbits the Sun, it also spins about its axis in just less than 24 hours. Our planet exhibits other motions as well — the most dramatic is known as precession. You can see precession every time you spin a top. As the top begins to slow, it also starts to wobble on its axis. A gyroscope does exactly the same thing, and so does Earth. As a result, a line extending from Earth's North Pole slowly traces a large circle around the sky. It takes about 26,000 years to complete one precessional cycle.

Throughout the Earth's precessional cycle, different stars have served as a pole star, or the star that lies directly overhead when viewed from the North or South Pole. In 1000 B.C.E., ancient mariners such as the Phoenicians had no convenient pole star to use for navigation. In the 5,000 to 6,000 years of recorded human history, Polaris (Alpha [α] Ursae Minoris) is a relative newcomer to the job of pole marker.

The sides of the great pyramids of Egypt align with the four cardinal directions. In the 19th century, explorers discovered a small shaft in the largest pyramid that pointed to the North Celestial Pole. Four thousand years ago, Egyptian astronomers were using the star Thuban (Alpha Draconis) as their pole star. As the centuries crept by, Thuban appeared to drift away from the North Celestial Pole. Although it was never as close to the Celestial Pole as Thuban, Kochab (Beta [β] Ursae Minoris) served as the North Star around 2000 B.C.E. At the height of the Roman Empire, there was no conspicuous North Star. Ancient travelers and seafarers had to use other methods to determine the direction north.

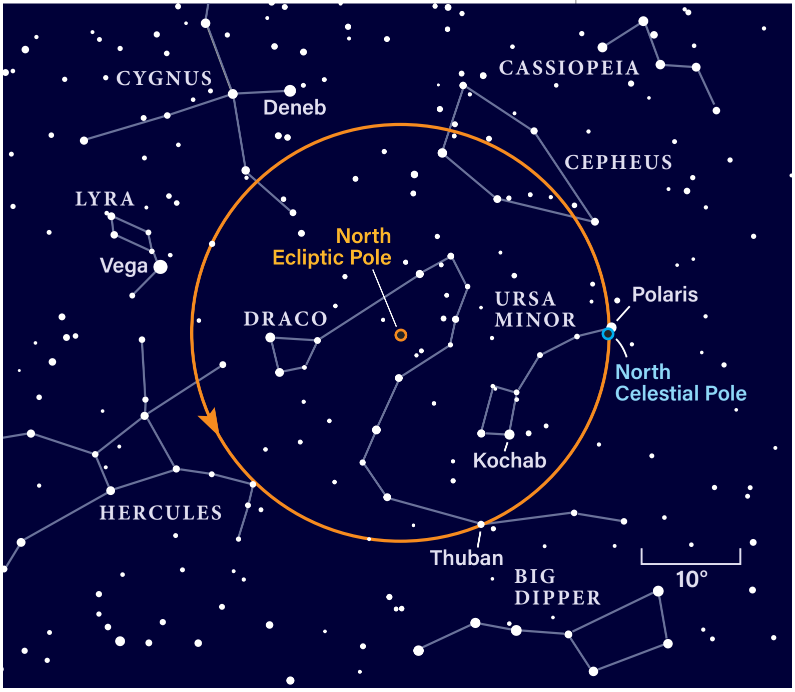
About 1,000 years ago, people began using Polaris as a standard for navigation. Alas, Polaris too will slip away from the Celestial Pole. In 14,000 years, the brilliant star Vega (Alpha Lyrae) will replace it. Vega is much brighter than Polaris, but it will never come as close to the Celestial Pole as the current North Star. At its best, Vega will be almost 10 Moon diameters away from that specific spot in the Northern Hemisphere.

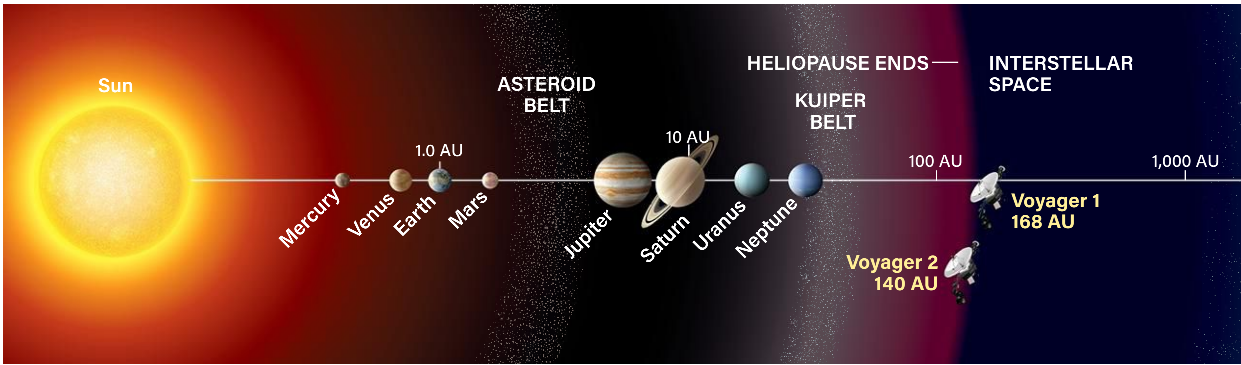
Raymond Shubinski
Contributing Editor



The illustration at left shows how Earth's spin axis (blue) is tilted from perpendicular, causing it to precess and trace out a circle over about 26,000 years. The brightest star nearest the North Celestial Pole is known as the North Star. Because the axis points in a different direction over time, as traced out by the orange circle in the illustration below, the identity of the North Star also changes, becoming the star closest to the orange outline at the time.

ASTRONOMY: ROEN KELLY (2)





This illustration shows the current positions of the Voyager missions with relation to the Sun. Currently considered outside the solar system, the spacecrafts will nonetheless take close to 300 years before reaching the Oort Cloud. The chances of either craft coming into contact with one of the comets located within the cloud is less likely than winning the lottery. *ASTRONOMY*: ROEN KELLY

Q WILL THE VOYAGER 1 AND VOYAGER 2 SPACECRAFT BE DAMAGED WHEN THEY FINALLY PASS THROUGH THE OORT CLOUD?

Terry Wilson
North Prince George, Virginia

A The Voyager 1 and Voyager 2 spacecraft were launched in 1977. Both passed Jupiter in 1979 and went on to Saturn a few years later, after which Voyager 2 also continued on to Uranus and Neptune. Eventually both entered interstellar space, leaving the heliopause — where the Sun's solar wind and the interstellar wind of the Milky Way Galaxy meet and are in balance — in August 2012 and November 2018, respectively. As of this writing, Voyager 1 is farther from Earth at nearly 168 astronomical units (AU) from the Sun because it is moving faster (11 miles [18 km] per second, or 3.6 AU per year) than its sister ship (which is moving at 10 miles [16 km] per second, or 3.3 AU per year). One AU is defined as the mean separation between Earth and the Sun, or 93 million miles (150 million kilometers). For reference, Earth's orbital speed around the Sun is about 6.3 AU per year (19 miles [30 km] per second).

In 1950, Leiden University astronomer Jan Hendrik Oort theorized the existence of a cloud of comets beyond some 10,000 AU from the Sun, possibly filling the volume dominated by the Sun's gravitational influence in the Milky Way Galaxy. This volume is an almost spherical bubble stretching as far as 100,000 AU. In comparison, the distance of the nearest star, Proxima Centauri, is about 270,000 AU (4.24 light-years).

So far, the Oort Cloud has not been observed directly, but many visiting comets originate from this enigmatic region. Oort estimated that the cloud would contain some 100 billion comet-sized objects (meaning a radius of 6.2 miles [10 km]). The total mass would be roughly comparable to Earth's. Some comets, such as Hale-Bopp, are much larger and more massive, but smaller comets are most common.

With a 6.2-mile (10 km) radius, a comet has a surface area of about 116 square miles (300 square km). If we spread out all 100 billion comets, they would cover a surface area roughly comparable to the Sun's surface. Now imagine that each of these comets is lifted from the Sun's surface to a distance of 10,000 AU, the inner edge of the Oort Cloud. Each comet will then become separated from its neighbors and the surface area covered by them drops by a factor of about $1/10^{13}$.

If this is difficult to imagine, here's a more earthly example: Compare the comets in the Oort Cloud to the 96 million black styrofoam balls dumped in 2015 in the Los Angeles reservoir to prevent evaporation. If we spread those styrofoam balls over the entire Earth's surface, the probability of finding one of them in your garden is comparable to winning the jackpot in a lottery. These odds are still 100,000 times larger than the probability of Voyager hitting a comet.

Simon Portegies Zwart
Professor of Computational Astrophysics,
Leiden University, Netherlands

Q BEFORE SPACECRAFT MISSIONS, HOW DID ASTRONOMERS DETERMINE THE MASS, SIZE, AND COMPOSITION OF THE GIANT PLANETS (JUPITER, SATURN, URANUS, AND NEPTUNE)?

K. Qureshi
Calgary, Alberta

A Excellent question. Astronomers are often faced with seeking information about objects they cannot visit to examine. Instead, they use mathematical laws and observation to determine the characteristics of the planets.

Determining the size of a celestial object is relatively straightforward, provided that one knows the object's distance and the angle it subtends from our viewpoint. Even though the planets Jupiter and Saturn have been known since antiquity, their distances in terrestrial units (i.e., miles or kilometers) weren't reliably

SEND US YOUR QUESTIONS

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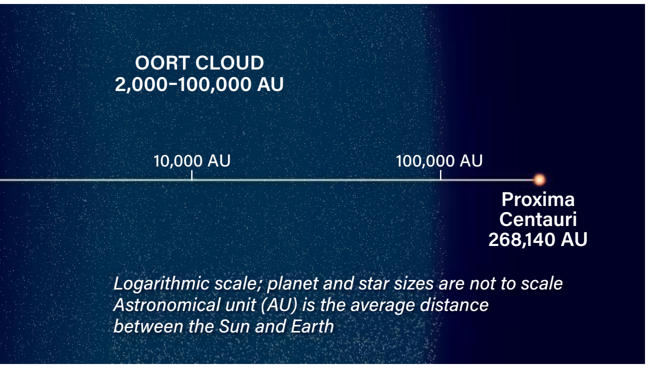


Logarithmic scale; planet and star sizes are not to scale
Astronomical unit (AU) is the average distance between the Sun and Earth

determined until 18th-century astronomers used two transits of Venus (in 1761 and 1769) to first measure the astronomical unit, or AU, in terrestrial units. Prior to these measurements, Kepler's third law (1619) enabled astronomers to determine the distances to the other planets in terms of the AU, but not in terms of terrestrial units. For instance, astronomers knew Jupiter's average heliocentric distance was 5.2 AU — 5.2 times farther from the Sun than Earth is. And once the AU was determined in miles, so too were the distances to Jupiter and all the other known solar system worlds. This information, combined with observations of the planets' angular diameters, which are readily discernible with a telescope, yielded direct measurements of their sizes.

Ascertaining a planet's mass requires nothing more than an orbiting body — e.g., a moon. Fortunately, the outer planets have these in abundance. Astronomers can use Newton's 1687 modification of Kepler's third law to determine the masses of both a parent body and a body in orbit around it: $P^2 = [4\pi^2/G(M_1+ M_2)]*a^3$

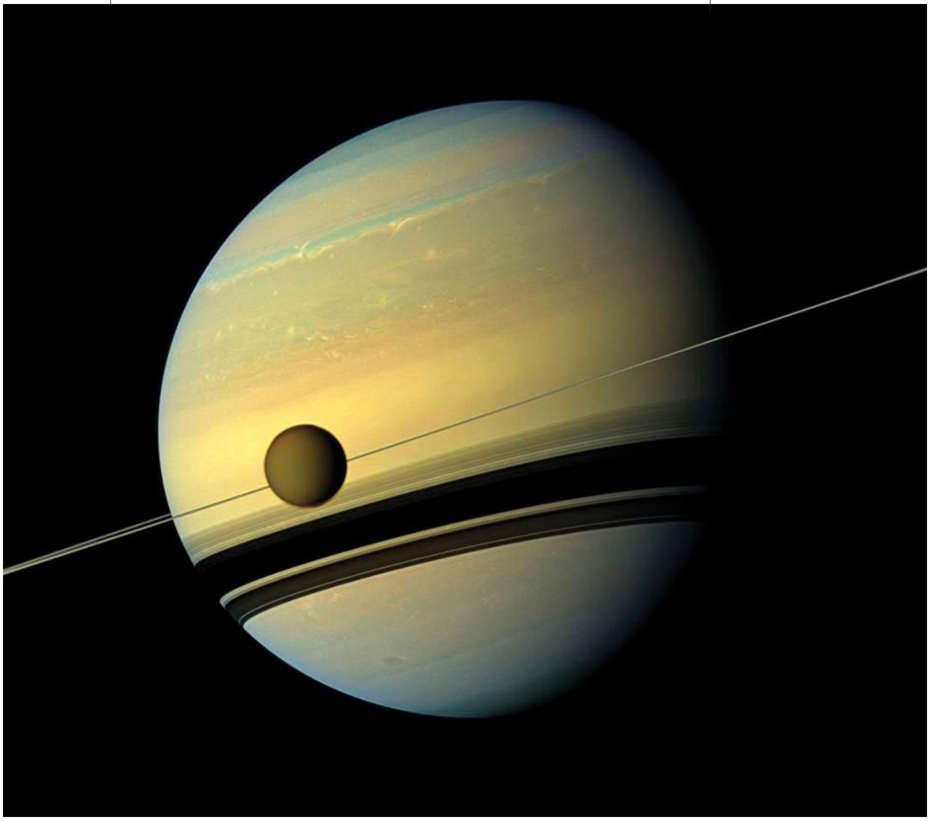
Here, P is the moon's orbital period, G is the gravitational constant, M_1 is the planet's mass, M_2 is the moon's mass, and a is the mean separation between the planet and its moon. By measuring a moon's orbital period and determining the separation from its planet, one can calculate the combined mass of both bodies. Fortunately, the masses of moons tend to be negligible in relation to their planets (Earth's moon is a notable exception), so in the case of the outer planets, the measurement of both masses essentially yields the planet's mass.

Jupiter's four Galilean moons were discovered in 1610. Saturn's moon Titan was discovered in 1655. William Herschel discovered Uranus in 1781 and in 1787 also discovered its moons Titania and Oberon. William Lassell discovered Neptune's largest moon, Triton, in 1846, very soon after the planet itself was discovered. As soon as astronomers were able to measure the orbital periods of these moons, they could determine the masses of the planets around which they revolved.

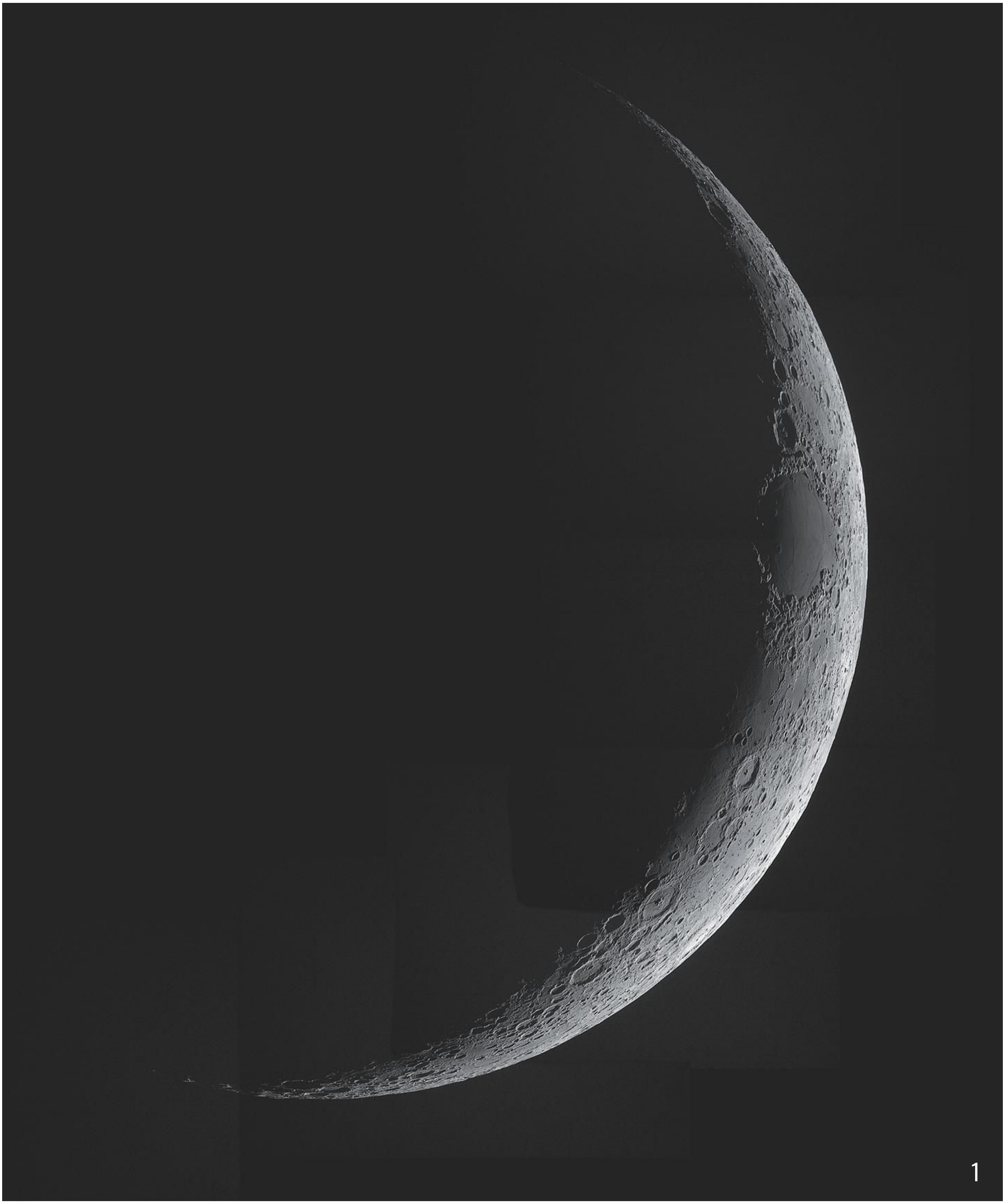
As for composition, astronomers can identify chemicals in the atmospheres of other planets through spectroscopy, or analysis of their light broken up by wavelength, called a spectrum. When astronomers observe the Sun's spectrum, they see a series of dark lines located at specific wavelengths. These dark lines are produced by the absorption of photons by the chemicals present in the outer regions of the Sun. Each chemical produces its own unique absorption spectrum. Think of these absorption patterns as akin to barcodes, each of which is associated with a given chemical.

We see the planets because they all reflect a portion of the sunlight they receive out into space. That reflected light, when split into a spectrum, also includes dark lines produced due to the absorption of light by chemicals in the planet's atmosphere. This reflected spectrum yields some direct information about the chemical composition of the outer planets' gaseous atmospheres.

Edward Herrick-Gleason
Astronomy Educator, St. John's, Newfoundland and Labrador



Titan is seen here crossing in front of Saturn. It is the planet's largest moon. Its discovery in 1655, allowed astronomers to determine Saturn's mass. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE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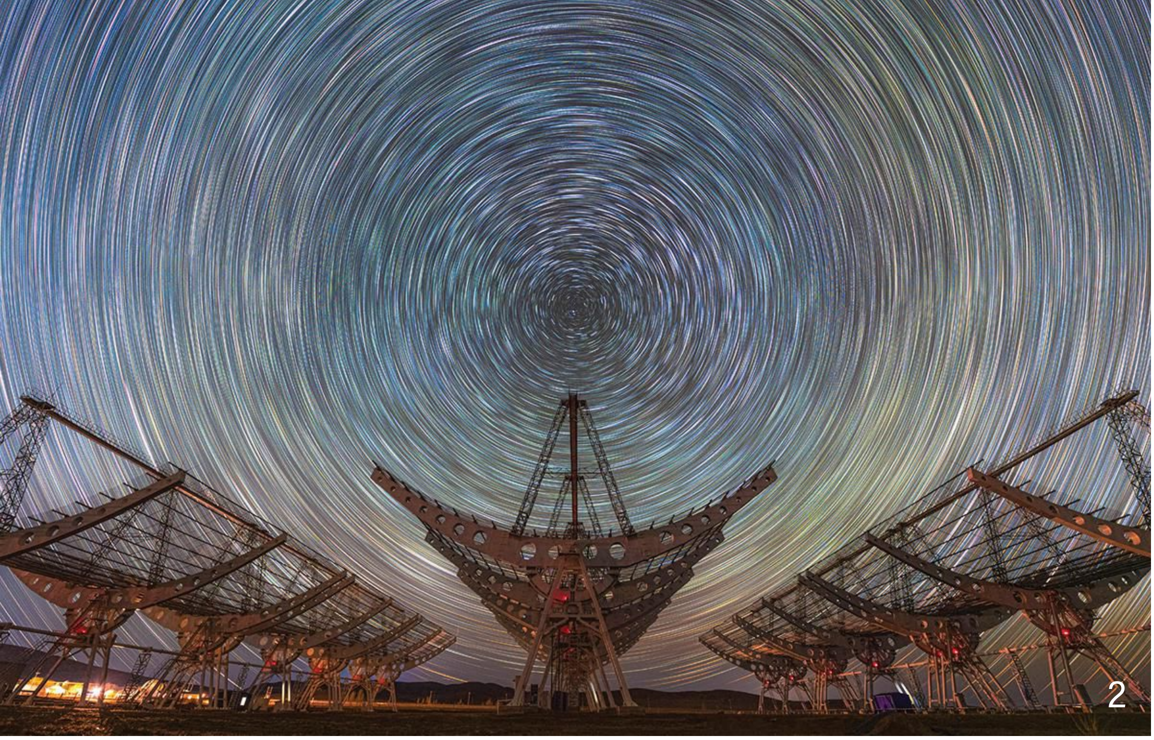
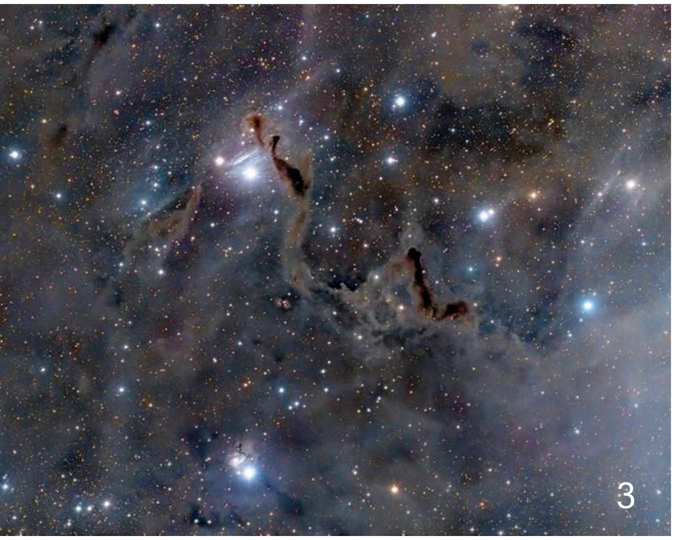
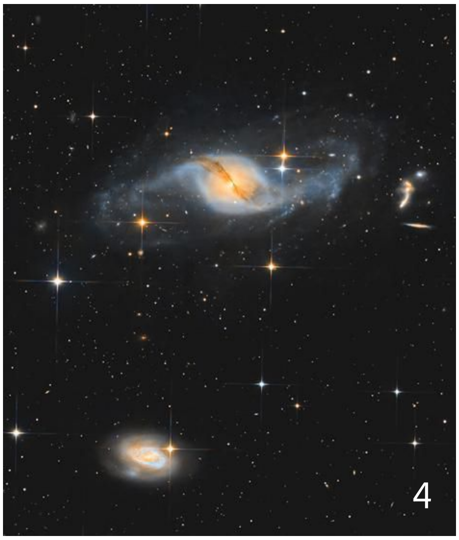
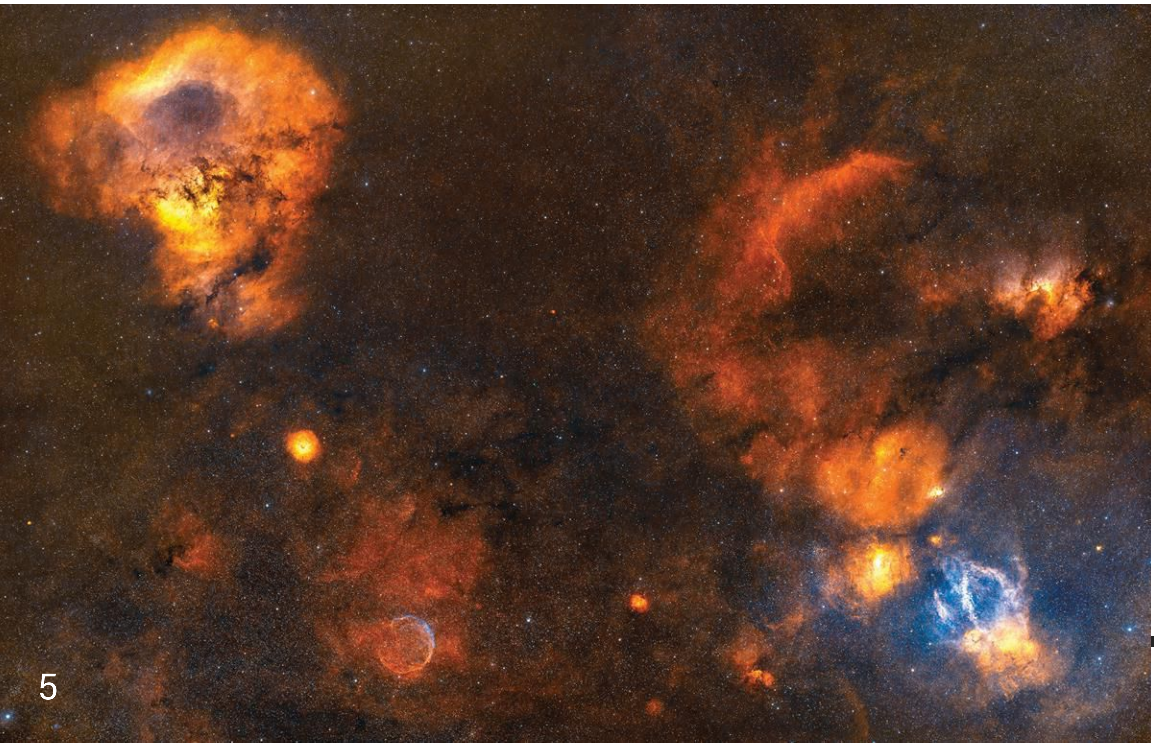








1. CRISES REVEALED
Dawn breaks over Mare Crisium (Sea of Crises), the prominent basin in the center of the young crescent Moon captured in this six-panel mosaic.
• Jamie Cooper

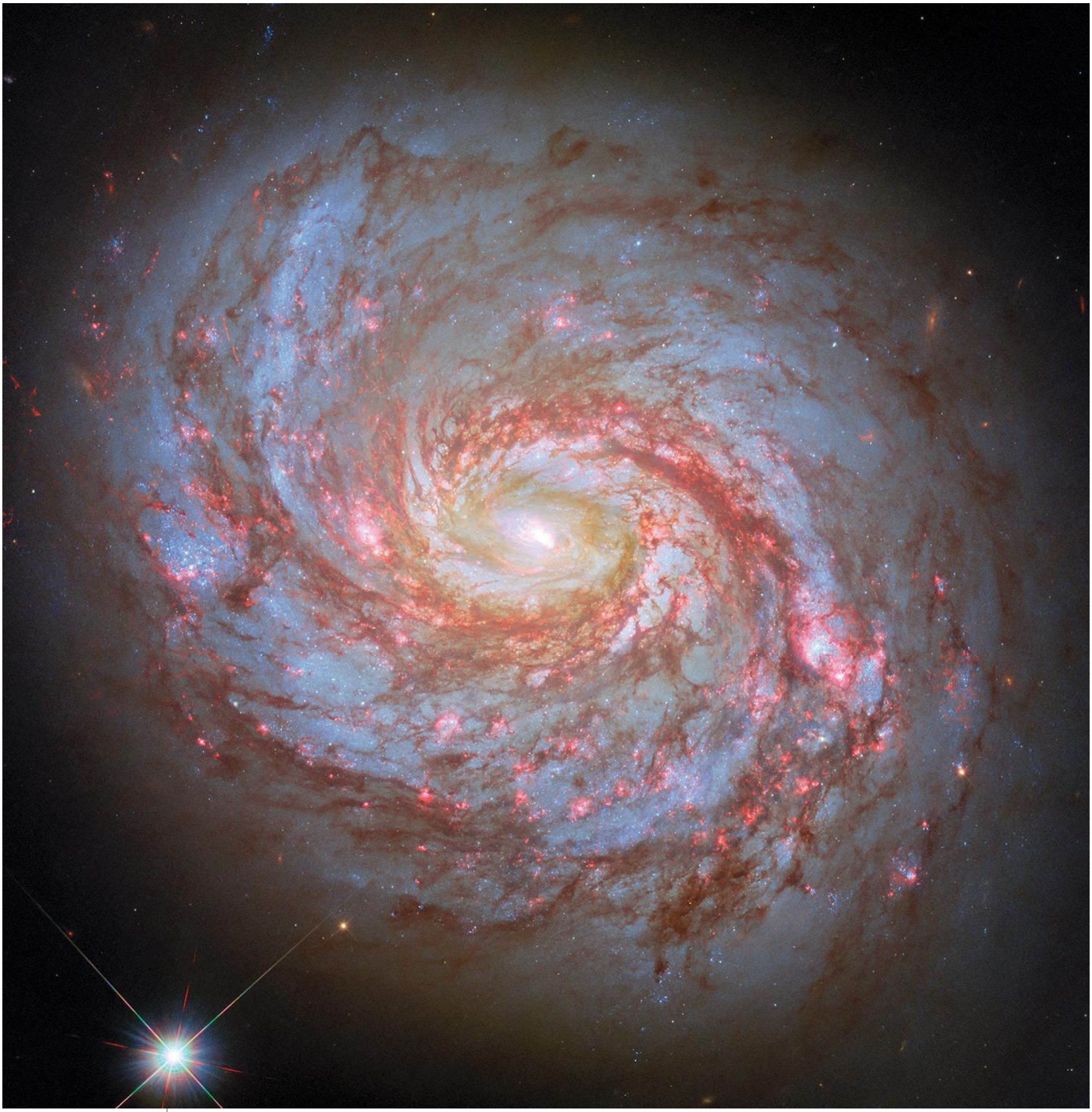
2. SCINTILLATING STAR TRAILS
Stars spin above the north-south-aligned antennas of the Interplanetary Scintillation Observation Telescope in Inner Mongolia, China's first radio telescope designed to study radio waves propagating through the solar wind. The imagers used a Sony mirrorless camera and 14mm lens, with 15-second exposures at f/3.2 and ISO 5000. ***• Huang Dandan/Liu Dongyu***

3. NEED A HAND?
Resembling an upturned palm, the Helping Hand Nebula in Cassiopeia consists of the dark nebulae LDN 1355/7/8, which overlie a region of reflection nebulosity cataloged as LBN 643. This imager took nine hours of exposure through a 4.2-inch scope in LRGB filters.
• Behyar Bakhshandeh

4. A TWISTED GALAXY
NGC 3718 is a barred spiral galaxy with an unusual, twisted shape — likely due to interactions with nearby NGC 3729 (below). Lying around 120 million light-years away, it's also listed as the 214th entry in Halton Arp's *Atlas of Peculiar Galaxies*. This image required 37⅓ hours of LRGB data from two 8-inch reflectors.
• Emil Andronic

5. GROUP PHOTO
This wide-field vista spans the constellations Cepheus and Cassiopeia and includes a host of deep-sky objects (from left to right): NGC 7822 (the Question Mark Nebula), LBN 576 (the Garlic Bulb Nebula), NGC 7635 (the Bubble Nebula), Sharpless 2–157 (the Lobster Claw Nebula), and Sharpless 2–155 (the Cave Nebula). The imager took 17 hours of data with a 2-inch scope, one-shot color camera, and $H\alpha$/OIII dual-band filter, presented here in an HOO palette. ***• Rob Lyons***

SEND YOUR IMAGES TO: readergallery@astronomy.com.
Please include the date and location of the image, your mailing address, and complete photo data: telescope, camera, filters, and exposures.



AN OCEAN OF LIGHT AND DARK

The face-on spiral galaxy M77 in Cetus the Whale explodes with detail in this Hubble image. Sites of intense star formation glow bright red and mingle with dark dust clouds to delineate the spiral arms. The bluish haze pervading the structure comes from billions of hot young stars. M77's tightly wound arms look a bit like the tentacles of a giant sea creature, which led to the object's nickname of the Squid Galaxy. Its bright nucleus marks M77 as a Seyfert galaxy, an active galaxy that radiates strongly at many wavelengths as matter swirls around a supermassive black hole. The one in M77 holds about 15 million solar masses. The Squid Galaxy ranks among the closest (45 million light-years away) and brightest (magnitude 8.9) Seyferts in the sky. ESA/HUBBLE & NASA, L.C. HO, D. THILKER

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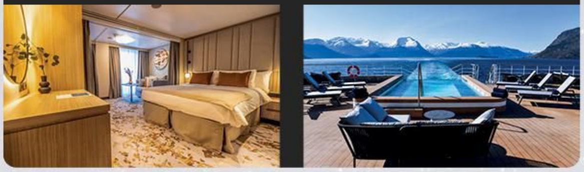

AUGUST 2026

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Siwa Oasis: Head out into the Western Deserts of Egypt and discover lush palm trees, crystal clear springs and serene salt lakes that paint a picturesque backdrop against the golden sands of the Sahara.

Luxor: The ancient capital of Egypt where history is measured in many thousands of years and there is much to see. You will certainly be sure to remember seeing a total solar eclipse from a private island in the Nile!

The Red Sea: Cooled by a gentle sea breeze, you can watch the eclipse from a high grade resort and indulge in snorkeling or diving in the remote and unspoilt colourful coral reefs.

Nile Cruise: This most famous of rivers tells its own story as you watch a panorama of history and daily life unfold along the banks, with a guiding hand from our expert guides of course!

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SOUTHERN SKY

BY MARTIN GEORGE

October 2025

Saturn rules the evening sky

Saturn takes center stage once darkness falls in October. Although the ringed world reached opposition and peak visibility in late September, the view this month is almost as good. The magnitude 0.7 planet lies in the northeastern corner of Aquarius the Water-bearer and appears far brighter than any nearby star. This area climbs highest in the north in late evening.

Saturn's icy rings always bring a thrill to backyard observers. Yet the excitement is muted a bit in October because the rings appear nearly edge-on. They tilt 1.5° to our line of sight on the 1st and just 0.6° on the 31st. With the rings creating less distraction, look for subtle atmospheric detail on the planet itself. Saturn's moons also become easier to spot with the reduced glare from the rings. Titan shows up through any telescope, while Tethys, Dione, and Rhea emerge in a good 10cm instrument.

As the month progresses, you can watch Mercury and Mars dance low in the western evening sky. **Mars** makes its final evening stand in October as it sinks deeper into twilight. The ruddy world appears only 4" across through a telescope, too small to show any detail.

The Red Planet's main interest this month is its approach to **Mercury**. The innermost planet becomes visible in early October and climbs into a darker sky as the month progresses. On the 19th, the two worlds stand side by side with just 2° separating them. Magnitude –0.2 Mercury lies to the left of its magnitude 1.5 sister world. Their official conjunction arrives 2 days later.

Mercury reaches greatest elongation Oct. 29, when it stands 24° east of the Sun and appears 11° high an hour after sundown. A telescope reveals the planet's 7"-diameter gibbous disk.

You'll have to wait until after midnight to see **Jupiter**. The giant planet appears against the backdrop of eastern Gemini, above that constellation's two brightest stars, Castor and Pollux. At magnitude –2.2, Jupiter easily outshines the stars in its vicinity.

The best views through a telescope come once the planet climbs higher with the approach of dawn. Jupiter spans 38" at midmonth and should show significant detail in its atmosphere. Meanwhile, its four bright moons — Io, Europa, Ganymede, and Callisto, all of which Galileo discovered in 1610 — stand out in any size scope. I often find Jupiter looks best with a touch of twilight in the sky, so you might want to try that trick.

The brightest planet hangs low in the east during morning twilight. **Venus** shines at magnitude–3.9 but stands only 5° above the horizon 30 minutes before sunrise. The inner planet won't look like much through a telescope. In mid-October, its disk appears 11" in diameter and nearly full.

A waxing crescent Moon occults 1st-magnitude Antares in Scorpius on Oct. 25. People in the southern part of South America can see an 11-percent-lit Luna overtake the red supergiant star and hide it from view for nearly an hour. From Punta Arenas, Chile, the pair lies low in the west-southwest in the early evening sky. Antares disappears behind the Moon's dark limb at 1h37m UT (locally the evening of the 24th) and reappears at 2h28m UT.

The starry sky

Pisces the Fish has always struck me as a curious constellation. Ancient skygazers developed several stories as to why a constellation with two fish even exists. Some suggest the two fish carried Eros and Aphrodite away from the danger posed by a monster called Typhon, or that Eros and Aphrodite were turned into fish themselves.

In October, the entire star group clears the northeastern horizon by midevening. Although Pisces' stars are rather faint, the constellation is easy to find this year because it lies directly below the prominent planet Saturn, which lies in neighboring Aquarius.

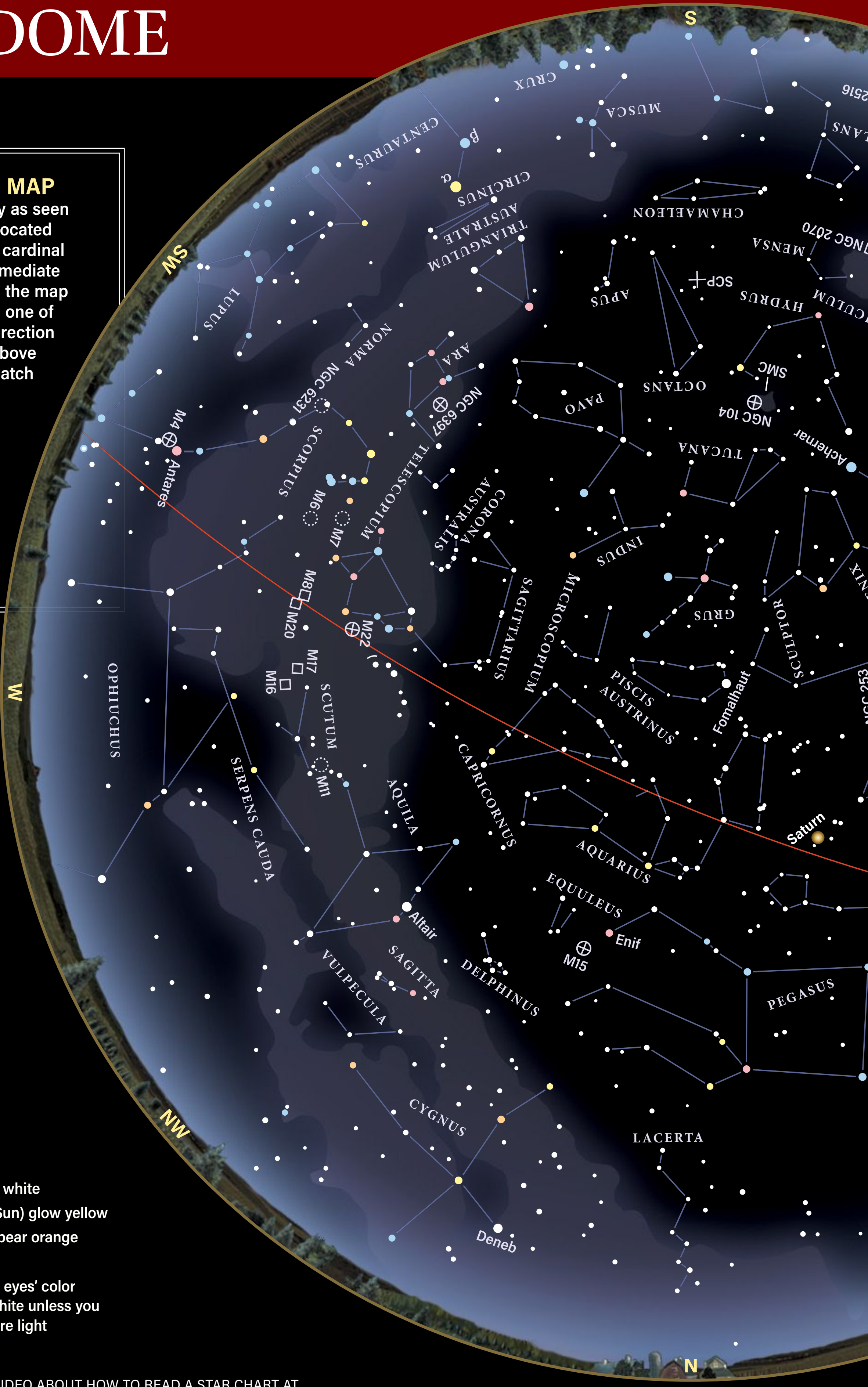
The fish stand a full 30° apart in the sky. An angled cord of stars, whose mythological origin and meaning remain obscure, joins the two. The northern fish lies well north of the celestial equator, at a declination of 30°. You can find it northwest (to the left) of the trio of bright stars Alpha (α), Beta (β), and Gamma (γ) Arietis.

The southern fish resides just north of the celestial equator. This collection of 4th- and 5th-magnitude stars creates a fairly conspicuous asterism known as the Circlet. The stars Iota (ι), Theta (θ), Gamma, Kappa (κ), and Lambda (λ) Piscium form a pattern close to a regular pentagon. The shape appears more rounded when you add 7 and TX Psc.

Although the Circlet asterism lies entirely north of the equator, a small chunk of Pisces south of this asterism extends to negative declinations. The cord connecting the two fish runs eastward from the Circlet to the magnitude 3.8 star Alrescha (Alpha Psc) at the constellation's southeastern corner. The star's name comes from an Arabic word meaning "the cord." A small telescope shows it to be a close binary comprising two whitish stars. A jagged line of fainter stars connects Alrescha with the northern fish.

The Circlet asterism also serves as a guide to locating the point on the sky known as the vernal equinox. This spot marks one of the two positions where the ecliptic — the apparent path of the Sun across our sky — crosses the celestial equator. The equinox lies some 5° southeast (to the lower right in October's evening sky) of the asterism.

STAR DOME


S
SW
W
NW
N
CRUX
MUSCA
CENTAURUS
β
α
CIRCINUS
TRIANGULUM AUSTRALE
CHAMAELEON
MENSA
NGC 2070
APUS
SCP
HYDRUS
LUPUS
NORMA
NGC 6231
ARA
NGC 6397
PAVO
OCTANS
SMC
NGC 104
Achernar
TUCANA
M4
Antares
SCORPIUS
M6
M7
TELESCOPIUM
CORONA AUSTRALIS
INDUS
GRUS
SCULPTOR
M8
M20
M22
SAGITTARIUS
MICROSCOPIUM
PISCIS AUSTRINUS
Fomalhaut
OPHIUCHUS
M17
M16
SCUTUM
M11
SERPENS CAUDA
AQUILA
CAPRICORNUS
AQUARIUS
Saturn
EQUULEUS
Enif
M15
Altair
SAGITTA
DELPHINUS
VULPECULA
PEGASUS
CYGNUS
LACERTA
Deneb

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth

MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

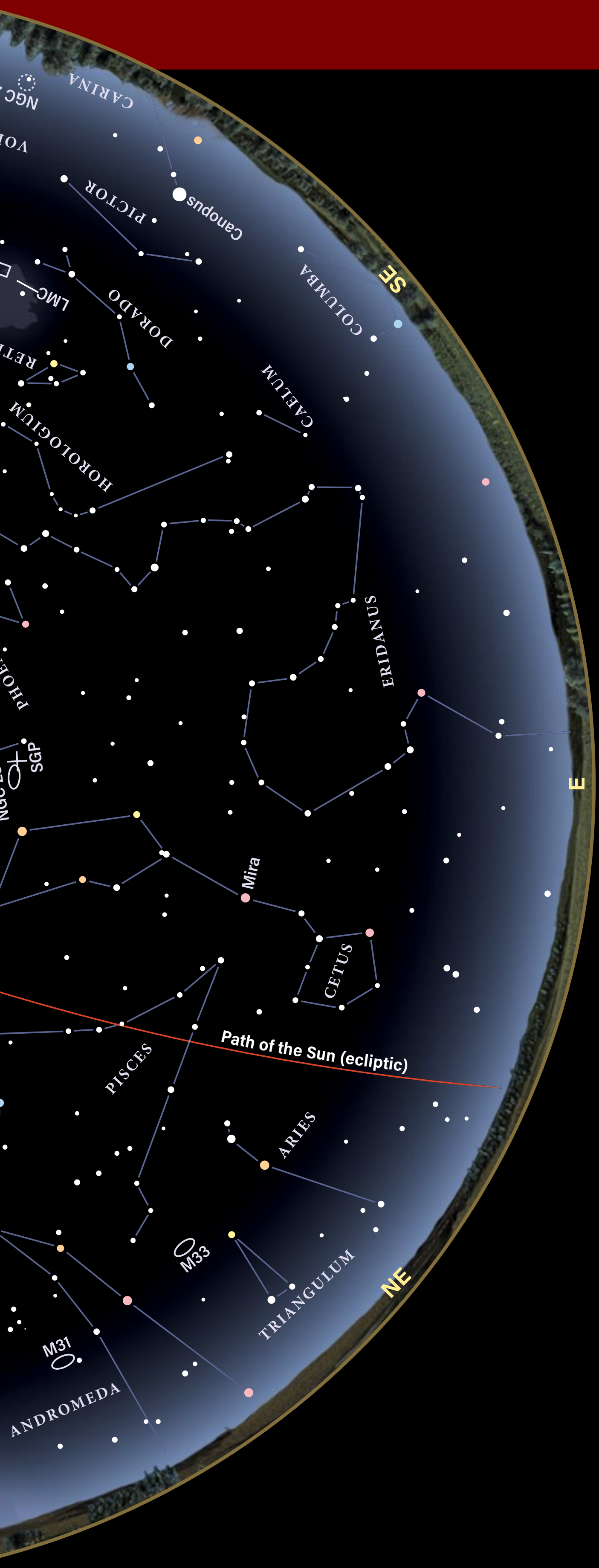
● Sirius
● 0.0
● 1.0
● 2.0
• 3.0
• 4.0
· 5.0

STAR COLORS

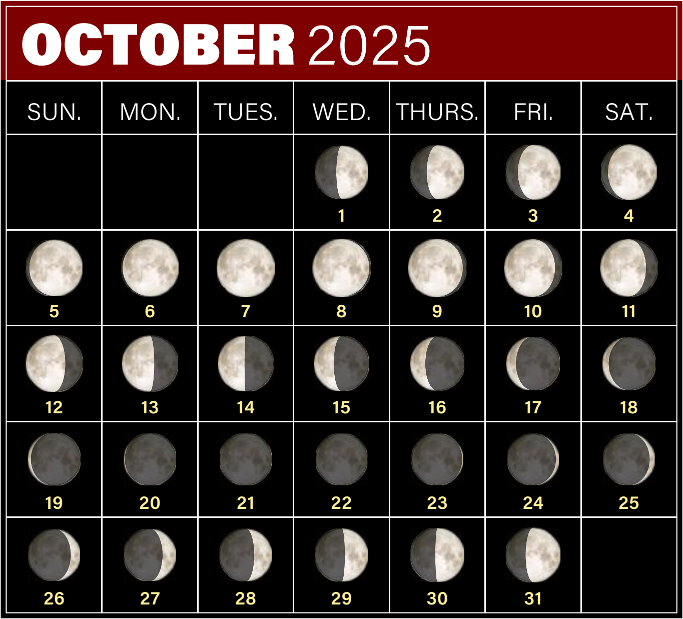
A star's color depends on its surface temperature.

- ■ The hottest stars shine blue
- ■ Slightly cooler stars appear white
- ■ Intermediate stars (like the Sun) glow yellow
- ■ Lower-temperature stars appear orange
- ■ The coolest stars glow red
- ■ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


NGC
CARINA
VOL
PICTOR
Canopus
LMC
DORADO
RETI
COLUMBA
SE
CAELUM
HOROLOGIUM
PHOE
SGP
ERIDANUS
E
Mira
CETUS
Path of the Sun (ecliptic)
PISCES
ARIES
M33
TRIANGULUM
NE
M31
ANDROMEDA

OCTOBER 2025



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

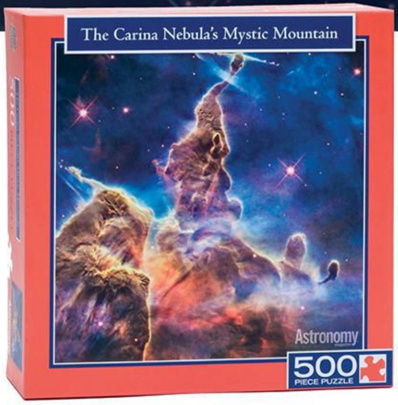
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1	The Moon passes 0.05° south of Pluto, 22h UT
2	Mercury passes 1.9° north of Spica, 11h UT
	Dwarf planet Ceres is at opposition, 13h UT
6	The Moon passes 4° north of Saturn, 3h UT
	The Moon passes 3° north of Neptune, 7h UT
7	Full Moon occurs at 3h48m UT
8	The Moon is at perigee (359,819 kilometers from Earth), 12h38m UT
10	The Moon passes 5° north of Uranus, 9h UT
13	Last Quarter Moon occurs at 18h13m UT
	The Moon passes 4° north of Jupiter, 22h UT
14	Pluto is stationary, 8h UT
16	The Moon passes 1.2° north of Regulus, 18h UT
19	The Moon passes 4° south of Venus, 22h UT
21	Mercury passes 2° south of Mars, 6h UT
	Orionid meteor shower peaks
	New Moon occurs at 12h25m UT
23	The Moon passes 5° south of Mars, 13h UT
	The Moon passes 2° south of Mercury, 16h UT
	The Moon is at apogee (406,444 kilometers from Earth), 23h30m UT
25	The Moon passes 0.5° south of Antares, 1h UT
27	Jupiter passes 7° south of Pollux, 15h UT
29	The Moon passes 0.1° north of Pluto, 7h UT
	First Quarter Moon occurs at 16h21m UT
	Mercury is at greatest eastern elongation (24°), 22h UT

EXPLORE THE UNIVERSE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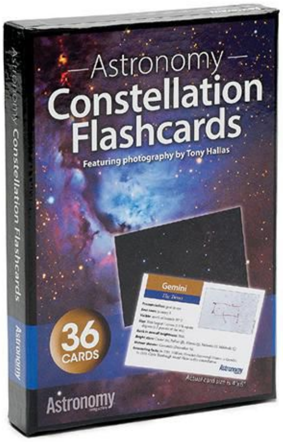
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The Milky Way from above
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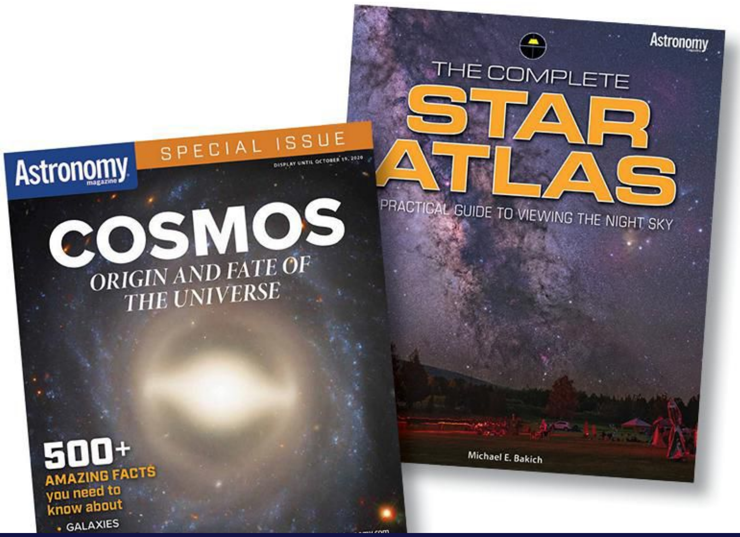
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